EXPLORATION OF THE SOLAR SYSTEM: FROM MERCURY TO PLUTO AND BEYOND

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

July 28, 2015

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July 28, 2015

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EXPLORATION OF THE SOLAR SYSTEM: FROM MERCURY TO PLUTO AND BEYOND

TUESDAY, JULY 28, 2015

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to call, at 10:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
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Congress of the United States
House of Representatives

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Committee on Science, Space, and Technology

Exploration of the Solar System: From Mercury to Pluto and Beyond

Tuesday, July 28, 2015
10:00 a.m. to 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. John Grunsfeld, *Associate Administrator, Science Mission Directorate, NASA*

Dr. Alan Stern, *Principal Investigator, New Horizons Mission, Southwest Research Institute*

Dr. Christopher Russell, *Principal Investigator, Dawn Mission; Professor of Geophysics and Planetary Physics, University of California Los Angeles*

Dr. Robert Pappalardo, *Study Scientist, Europa Mission Concept, Jet Propulsion Laboratory, NASA*

Dr. Robert Braun, *David and Andrew Lewis Professor of Space Technology, Georgia Institute of Technology*

U.S. House of Representatives
Committee on Science, Space, and Technology

Exploration of the Solar System: From Mercury to Pluto and Beyond

HEARING CHARTER

Tuesday, July 28, 2015
10:00 a.m.
2318 Rayburn House Office Building

Purpose

At 10:00 a.m. on Tuesday, July 28, 2015, the Science, Space, and Technology Committee will hold a hearing titled *Exploration of the Solar System: From Mercury to Pluto and Beyond.* The purpose of this hearing is to review recent NASA achievements in exploring our solar system, including the exploration of Pluto and the asteroid Ceres, as well as assess future NASA missions under development, including a flagship mission to conduct a detailed survey of Jupiter's moon Europa.

Witnesses

- **Dr. John Grunsfeld,** Associate Administrator, Science Mission Directorate, NASA
- **Dr. Alan Stern,** Principal Investigator, New Horizons Mission, Southwest Research Institute
- **Dr. Christopher Russell**, Principal Investigator, Dawn Mission, and Professor of Geophysics and Planetary Physics, University of California Los Angeles
- **Dr. Robert Pappalardo,** Study Scientist, Europa Mission Concept, Jet Propulsion Laboratory, NASA
- **Dr. Robert Braun,** David and Andrew Lewis Professor of Space Technology, Georgia Institute of Technology

Background

Budget for NASA's Science Mission Directorate[1]

	Actual	Enacted	Request	FY15 Vs FY16	Appropriations		Authorizations
					House	Senate	H.R. 2039 (Sec. 101)
Budget Authority ($ in millions)	**FY14**	**FY15**	**FY16**		**FY16**	**FY16**	**FY16**
Science	5,148	5,245	5,289	44	5,238	5,295	4,952
Earth Science	1,825	1,773	1,947	174	1,683	1,932	1,450
Planetary Science	1,346	1,438	1,361	(77)	1,557	1,321	1,500
Astrophysics	678	686	709	24	736	731	731
James Webb Space Telescope	658	645	620	(25)	620	620	620
Heliophysics	641	662	651	(11)	642	650	651

[1] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) <https://www.fas.org/sgp/crs/space/R43419.pdf>

The Science Mission Directorate (SMD) conducts scientific exploration enabled by the observatories and probes that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond.[2] SMD has four divisions; Astrophysics, Earth Science, Heliophysics, and Planetary Science. NASA is requesting $5.288 billion for SMD in FY16, an increase of approximately $43.9 million (0.8 percent) above the FY15 enacted level.

The Planetary Science Division is responsible for monitoring and analyzing data collected from NASA missions exploring the solar system in the search to ascertain the content, origin, the evolution of the solar system and potential for life on other worlds as well as the search for potentially hazardous Near Earth Objects. The budget for the Planetary Science division has decreased from $1.485 billion in the FY11 request to $1.361 billion in the FY16 request.[3] The Committee approved a two-year authorization of $1.5 billion in FY16 and FY17 for the Planetary Science division in H.R. 2039, the National Aeronautics and Space Administration Authorization Act of 2016 and 2017.[4] The House Representatives passed an FY16 appropriation for NASA's Planetary Science funding of $1.557 billion.[5] The Senate Committee on Appropriations reported $1.321 billion for NASA's Planetary Science division.[6]

NASA's FY16 budget request includes a line item of $30 million to support formulation of a new mission to explore Jupiter's moon, Europa, one of Jupiter's moons that is covered with frozen water. Since water is one of the fundamental ingredients for life on Earth, Europa holds promise that life may exist beyond Earth. Congress continues to demonstrate support for a Europa mission, one of the priorities from the National Academies of Science decadal survey for planetary science.[7]

New Horizons Mission

New Horizons is an interplanetary space probe that was launched as part of NASA's New Frontiers program to flyby at close range and image Pluto, gathering information about its atmosphere and surface features.[8] This is the first mission to examine Pluto and its moons Charon, Nix, Hydra, Kerberos, and Styx.

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[2] National Aeronautics and Space Administration FY16 Budget Estimates – Science Mission Directorate (p. SCMD-4) <http://www.nasa.gov/sites/default/files/files/NASA_FY_2016_Budget_Estimates.pdf>

[3] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) < https://www.fas.org/sgp/crs/space/R43419.pdf>

[4] H.R. 2039, *NASA Authorization Act of 2016 and 2017* < https://www.congress.gov/bill/114th-congress/house-bill/2039/text>

[5] H.R. 2578, *Commerce, Justice, Science and Related Agencies Appropriations Act, 2016* < https://www.fas.org/sgp/crs/space/R43419.pdf>

[6] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) < https://www.fas.org/sgp/crs/space/R43419.pdf>

[7] National Research Council. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. p. 268, Appendix C, p. 345. Washington, DC: The National Academies Press, 2011. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[8] New Horizons was the first New Frontiers program selected. Others include Juno (a mission to Jupiter) and Osiris-Rex (a mission to return an asteroid sample to Earth). All New Frontiers programs are principal-investigator led mission that are cost capped at approximately $1 Billion.

New Horizons was launched in 2006, and flew 12,500 kilometers/7,800 miles above Pluto on July 14th. The spacecraft is already to transmitting data recorded during the flyby. It will take 16 months for all data to be transmitted.[9] The total cost of New Horizons is approximately $700 million.[10]

New Horizons carries seven scientific instruments to study the surfaces of Pluto, its moons, and any Kuiper Belt objects that New Horizons encounters: a visible and infrared imager/spectrometer (RALPH), an ultraviolet imaging spectrometer (ALICE), a radio science experiment for studying atmospheres (REX), a telescopic camera (LORRI), a solar wind and plasma spectrometer (SWAP), an energetic particle spectrometer (PEPSSI) and a space dust counter (SDC).[11]

New Horizons scientific objectives are ranked into three categories, called Group 1, Group 2, and Group 3.[12]

- Group 1 objectives: (required)
  - Characterize the global geology and morphology of Pluto and Charon
  - Map chemical compositions of Pluto and Charon surfaces
  - Characterize the neutral (non-ionized) atmosphere of Pluto and its escape rate
- Group 2 objectives: (expected)
  - Characterize the time variability of Pluto's surface and atmosphere
  - Image select Pluto and Charon areas in stereo
  - Map the terminators (day/night border) of Pluto and Charon with high resolution
  - Map the chemical compositions of select Pluto and Charon areas with high resolution
  - Characterize Pluto's ionosphere (upper layer of the atmosphere) and its interaction with the solar wind
  - Search for neutral species such as molecular hydrogen, hydrocarbons, hydrogen cyanide and other nitriles in the atmosphere
  - Search for any Charon atmosphere
  - Determine bolometric Bond albedos for Pluto and Charon
  - Map surface temperatures of Pluto and Charon
  - Map any additional surfaces of outermost moons: Nix, Hydra, Kerberos, and Styx
- Group 3 objectives: (desired)
  - Characterize the energetic particle environment at Pluto and Charon
  - Refine bulk parameters (radii, masses) and orbits of Pluto and Charon
  - Search for additional moons and any rings

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[9] Greg Rienzi, *How exactly does New Horizons send all that data back from Pluto?* John Hopkins University Hub <http://hub.jhu.edu/2015/07/17/new-horizons-data-transmission>.
[10] NASA New Horizons website: <http://solarsystem.nasa.gov/missions/profile.cfm?MCode=PKB&Display=ReadMore>
[11] NASA New Horizons website: <http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Target&Target=Dwarf&MCode=PKB&Display=ReadMore>
[12] Harold A. Weaver and S. Alan Stern, *New Horizons: NASA's Pluto-Kuiper Belt Mission* at <http://web.gps.caltech.edu/~mbrown/out/kbbook/Chapters/Weaver_NewHorizons.pdf>

A potential extended mission could include traveling to the Kuiper Belt to study at least one Kuiper Belt object.

Current Planetary Missions[13]

In addition to New Horizons, Planetary Science missions currently in operation and/or development include, in alphabetical order:

Cassini-Huygens (Cassini Solstice Mission) – Cassini-Huygens was launched in 1997 and entered orbit around Saturn in 2004. Cassini is an orbiting spacecraft and Huygens is an atmospheric entry probe that landed on Saturn's moon Titan in 2005. The Cassini mission continues to conduct numerous fly-bys of Saturn's moons, including Enceladus and Titan, which may harbor environments conducive to the existence of life. Cassini is currently in its second mission extension called the Cassini Solstice Mission, examining the rings of Saturn and high-latitude mapping of Titan and Saturn. The total cost of the Cassini-Huygens mission is about $3.26 billion. The U.S. contributed $ 2.6 billion, the European Space Agency $500 million and the Italian Space Agency $160 million.[14]

Dawn – The Dawn mission's goal is to characterize the conditions and processes of the solar system's earliest eon by investigating in detail two of the largest proto-planets remaining intact since their formation. After launch in 2007, it orbited its first destination, the asteroid Vesta, in 2011, and reached its final destination the dwarf planet Ceres last March. The total cost of the Dawn mission (not including launch vehicle) is approximately $357.5 million.[15]

Europa –NASA recently initiated a mission to study Jupiter's icy moon Europa. The mission would send a solar-powered spacecraft into a long, looping orbit around the gas giant Jupiter to perform repeated close flybys of Europa over a three-year period. Last May, NASA selected nine science instruments for a mission to Jupiter's moon Europa, to investigate whether the mysterious icy moon could harbor conditions suitable for life.[16]

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[13] Please note that the cost numbers provided in this section are designed to give an accurate understanding of program costs, but may not include mission extension costs or other costs that have been incurred since the mission launched. Also, the cost numbers cited are not recalculated to account for current value of money. For example, the cost to a mission cited from a press kit in 2005 will not be recalculated into 2015 dollars.

[14] NASA Cassini website: <http://saturn.jpl.nasa.gov/faq/FAQMission/>

[15] NASA Dawn website <http://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=Dawn&Display=ReadMore>

[16] The instruments NASA selected are: Plasma Instrument for Magnetic Sounding (PIMS) -- principal investigator Dr. Joseph Westlake of Johns Hopkins Applied Physics Laboratory (APL), Laurel, Maryland; Interior Characterization of Europa using Magnetometry (ICEMAG) -- principal investigator Dr. Carol Raymond of NASA's Jet Propulsion Laboratory (JPL), Pasadena, California; Mapping Imaging Spectrometer for Europa (MISE) -- principal investigator Dr. Diana Blaney of JPL; Europa Imaging System (EIS) -- principal investigator Dr. Elizabeth Turtle of APL; Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) -- principal investigator Dr. Donald Blankenship of the University of Texas, Austin; Europa Thermal Emission Imaging System (E-THEMIS) -- principal investigator Dr. Philip Christensen of Arizona State University, Tempe; MAss SPectrometer for Planetary EXploration/Europa (MASPEX) -- principal investigator Dr. Jack (Hunter) Waite of the Southwest Research Institute (SwRI), San Antonio; Ultraviolet Spectrograph/Europa (UVS) -- principal investigator Dr. Kurt Retherford of SwRI; SUrface Dust Mass Analyzer (SUDA) -- principal investigator Dr. Sascha Kempf of the University of Colorado, Boulder.

There is no firm cost estimate yet for the Europa mission, but it is likely to be a "flagship" class mission for NASA over $1 billion.

InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) – InSight is a Mars lander mission, and is expected to launch in spring 2016. It will study the interior of Mars to understand how rocky planets (like Earth and Mars) were formed, and investigate possible tectonic activity. The mission (not including launch vehicle) is cost-capped at $425 million.[17]

Juno – Juno will orbit over Jupiter's poles to study Jupiter's composition, gravity field, magnetic field, and polar magnetosphere and search for clues about how the planet formed, including whether it has a rocky core, the amount of water present within the deep atmosphere, and how its mass is distributed. It will be the first solar-powered spacecraft to orbit Jupiter. Juno launched in 2011 and is scheduled to arrive at Jupiter in 2016. Total cost is approximately $1.1 billion.[18]

JUICE (Jupiter Icy Moons Explorer) – In a partnership with the European Space Agency (ESA), this mission will explore Jupiter and its moon Ganymede. NASA's contribution will consist of one U.S.-led science instrument and hardware for two European instruments to fly on ESA's Jupiter Icy Moons Explorer (JUICE) mission. It is expected to launch in 2022 and reach Jupiter in 2030. NASA's total contribution to the JUICE mission is $100 million.[19]

LRO (Lunar Reconnaissance Orbiter) – LRO orbits the Moon, and was launched in 2009 as a precursor to future human and robotic missions to the lunar surface. One of its primary purposes was to map potential landing sites for future human Moon exploration, but it also has provided more information about the Moon's geological features and the potential presence of ice and water. LRO is currently active on an extended mission. The total cost is approximately $500 million.[20]

MAVEN (Mars Atmosphere & Volatile EvolutioN) – MAVEN is part of NASA's Mars Scout program to study Mars's upper atmosphere, ionosphere and interactions with the sun and solar wind. MAVEN reached Martian orbit in 2014. Mission goals include determining how the atmosphere of Mars and water, presumed to have once been substantial, were lost over time. The total cost is approximately $671 million.[21]

Opportunity Rover (Mars Exploration Rover/MER) – Opportunity is one of two Mars Exploration Rovers (the other being named Spirit). landed on Mars in 2004 and continues to move, gather scientific observations (including evidence of Mars' habitable past), and

[17] NASA InSight website: <http://www.nasa.gov/mission_pages/mars/news/mars20120820.html>
[18] NASA Juno website <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=Juno&Display=ReadMore>
[19] NASA JUICE website: <http://www.nasa.gov/home/hqnews/2013/feb/HQ_13-060_JUICE_Instruments.html>
[20] NASA LRO website: <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=LRO&Display=ReadMore >
[21] NASA Maven website: <http://mars.nasa.gov/files/resources/MAVEN_PressKit_Final.pdf >

report back to Earth for over 4075 sols.[22] 40 times longer than originally planned. The total cost for the Mars Exploration Rover program is approximately $820 million.[23]

Mars Express – Mars Express is a European Space Agency (ESA) mission, launched in 2003 and successfully orbiting Mars in 2004. The U.S. contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and the Analyzer of Space Plasmas and EneRgetic AtomS (ASPERAS). These instruments examine the ionosphere and atmosphere of Mars to determine the potential for life on the planet. The mission is operational. Mars Express cost approximately $300 million euros, including scientific payloads and launch.[24]

Mars Odyssey 2001 – Measurements made by the orbiting spacecraft Mars Odyssey have enabled scientists to create a mineralogical map that provides future missions with target areas in which to search for the potential existence of water, microbial life, and possible landing sites for human missions to the surface of Mars. It is still operating on an extended mission. Total cost is approximately $297 million.[25]

MOMA (Mars Organic Molecule Analyzer) – This instrument is the U.S. contribution to the ESA ExoMars program (Exobiology on Mars). It is the astrobiology instrument on Europe's 2018 Mars rover. ExoMars is expected to cost approximately $1.2 billion euros.[26]

MRO (Mars Reconnaissance Orbiter) – Launched in 2005, MRO has a powerful camera with which it captures detailed pictures of Mars' geology. The pictures are being used to determine possible future landing sites. MRO has provided photographic evidence of the existence of liquid on Mars. It also serves as a communication relay between Mars and Earth for the Mars rovers. Total cost is approximately $720 million.[27]

Mars Rover 2020 – This mission is part of NASA's Mars Exploration Program, scheduled to be launched in 2020. The rover will collect core samples for future return to Earth, conduct fine-scale imaging, determine mineral and chemical compositions, and determine the existence of past or present organic material. It will also conduct tests to determine if the right ingredients exist on Mars for production of oxygen for human use. Preliminary estimate of project life cycle cost is $2.14-$2.35 billion.[28]

Curiosity Rover (Mars Science Laboratory Curiosity Rover) – Curiosity is NASA's largest rover on Mars and is collecting soil and rock samples and analyzing them to determine if conditions have existed to support microbial life. It has already found

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[22] The term sol is used by planetary astronomers to refer to the duration of a solar day on Mars.
[23] NASA MER website: <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=MER&Display=ReadMore >
[24] ESA Mars Express press kit <http://www.esa.int/esaSC/SEMTV8374OD_0_spk.html >
[25] NASA Odyssey press kit <http://www.jpl.nasa.gov/news/press_kits/odysseyarrival.pdf >
[26] Stephen Clark, *Facing Funding Gap, ExoMars Rover is on Schedule for Now,* Spaceflightnow.com <http://www.spaceflightnow.com/news/n1403/03exomars/#.Va_M0PlVhBc >
[27] NASA MRO press kit < http://www.nasa.gov/pdf/124378main_mro-launch-Aug051.pdf >
[28] GAO, *NASA Assessments of Selected Large-Scale Projects* (GAO-15-320SP) <http://www.gao.gov/products/GAO-14-338SP>

evidence that water flowed on the Martian surface that could have supported microbial life. The total cost is approximately $2.5 billion.[29]

MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) – MESSENGER was a robotic NASA spacecraft which orbited the planet Mercury between 2011 and 2015. The scientific objectives of the mission were to characterize the chemical composition of Mercury's surface, to study the planet's geological history, to elucidate the nature of the global magnetic field, to determine the size and state of the core, to determine the volatile inventory at the poles, and to study the nature of Mercury's exosphere. Operations are complete but scientists are still analyzing data from the mission. Total cost is approximately $460 million.[30]

NEOWISE (Near Earth Object Wide-field Infrared Survey Explorer) - NEOWISE is a NASA infrared-wavelength astronomical space telescope launched in December 2009, and placed in hibernation in February 2011 when its transmitter turned off. It was re-activated in 2013 on a new three-year mission to search for potentially hazardous near-Earth objects. Total cost is approximately $300 million.[31]

OSIRIS-REx (Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer) –The spacecraft is scheduled to launch in 2016 and will examine the asteroid Bennu and return a physical sample of the asteroid to Earth. It is the third planetary science mission selected in the New Frontiers Program, after Juno and New Horizons. The development cost of Osiris-Rex is estimated at $709.7 million.[32]

Rosetta – Rosetta is a European Space Agency (ESA) led mission that rendezvoused and landed *Philae* on Comet Churymov-Gerasimenko (C-CG) in 2014. NASA contributed three instruments to Rosetta. After escorting comet C-CG past its perihelion (closest point to the Sun), Rosetta will terminate its mission. The total cost is close to $1.4 billion Euros.[33]

Planetary Decadal Survey Recommendations

The most recent decadal survey, Visions and Voyages for Planetary Science in the Decade 2013- 2022 was issued in March 2011 ("2013 Planetary Science Decadal Survey"). Requested by NASA, and managed and written by the National Academy of Sciences, the report develops a comprehensive strategy for U.S. planetary science in the coming decade. Per the report, the recommended program "will achieve long-standing scientific goals with a suite of new missions across the solar system. It will provide fundamental new scientific knowledge, engage a broad segment of the planetary science community, and have wide appeal for the general public whose support enables the

[29] NASA Curiosity website
<http://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=MarsSciLab&Display=ReadMore>
[30] NASA Messenger website
<http://solarsystem.nasa.gov/missions/profile.cfm?MCode=MESSENGER&Display=ReadMore>
[31] NASA NEOWISE website
<https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=WISE&Display=ReadMore>
[32] GAO, *NASA Assessments of Selected Large-Scale Projects* (GAO-15-320SP)
[33] ESA Rosetta website
<http://www.esa.int/Our_Activities/Space_Science/Rosetta/Frequently_asked_questions >

program."[34] The 2013 Planetary Science Decadal Survey committee utilized four main criteria to measure proposed missions as a means of selecting and prioritizing future missions. First and foremost was the ability to provide high science return per dollar. Programmatic balance across mission targets throughout the solar system as well as the appropriate mix of small, medium and large missions was the second criteria. The other two criteria were technological readiness and the availability of trajectory opportunities within the timeframe discussed.

Discovery-class Planetary Mission Announcement of Opportunity

Discovery-class missions in the Planetary Science division are cost-capped, competitively awarded, smaller and less-expensive missions that explore the Solar System. Missions are proposed and led by a senior scientist who serves as the Principal Investigator (PI) for the mission. In selecting Discovery missions, consideration is given to the priorities outlined in the latest planetary science decadal survey issued by the National Academies of Science.[35] The 2013 Planetary Science Decadal Survey does not make specific recommendations on the small Discovery program missions. It does register its continued support for these missions as a valuable asset to the overall program and recommends that it continue at its current level capped at $500 million (FY2015) and a cadence of 24 months for selections.

Last November, NASA released their Discovery-class Planetary Mission Announcement of Opportunity (AO). The deadline for submitting proposals was February 2015. The latest AO for Discovery-class missions is the thirteenth announcement. The cost cap for Discovery missions is $450 million, not including the cost of the launch vehicle. The mission must be ready for launch no later than December 31, 2021.

To date, NASA has not announced a selected mission for the 2014 Discovery-class Planetary Mission AO.

New Frontiers-class Planetary Mission Announcement of Opportunity

Medium missions, known as New Frontiers, are capped at $1 billion (FY2015) per mission (excluding launch vehicle costs) with a goal of selecting two such missions in the decade. Based on their science value and projected costs, the 2013 Planetary Science Decadal Survey committee recommended NASA select two additional New Frontiers missions in the decade 2013-2022 (referred to as New Frontiers Mission 4 and New Frontiers Mission 5). "To achieve an appropriate balance among small, medium, and large missions, NASA should select two New Frontiers missions in the decade 2013-2022."[36] The report identifies five candidate missions and two alternates for which

[34] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. ES-1 <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[35] *Visions and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[36] *Visions and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. Pg. 15. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

NASA should select based on competitive peer review. Candidate missions include Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour and Rendezvous and Venus In Situ Explorer. The alternates would be Io Observer and Lunar Geophysical Network.

NASA's FY16 budget requests funding for a 2016 New Frontiers AO. NASA plans to announce the next opportunity by the end of FY 2016.[37]

Flagship Missions

Flagship missions are the largest and most expensive of NASA's solar system exploration programs, costing more than $1 billion each. The 2013 Planetary Science Decadal Survey identified five candidate flagship missions for the decade 2013-2033. In alphabetical order, they are as follows:[38]

- **Enceladus Orbiter:** This mission would investigate the saturnian satellite's cryovolcanic activity, habitability, internal structure, chemistry, geology, and interaction with other bodies of the Saturn system.
- **Jupiter Europa Orbiter (JEO):** This mission would characterize Europa's ocean interior, ice shell, chemistry and composition, and the geology of prospective landing sites.
- **Mars Astrobiology Explorer-Cacher (MAX-C):** This mission is the first of the three components of the Mars Sample Return campaign. It is responsible for characterizing a landing site selected for high science potential, and for collecting, documenting, and packaging samples for return to Earth.
- **Uranus Orbiter and Probe:** This mission's spacecraft would deploy a small probe into the atmosphere of Uranus to make in site measurements of noble gas abundance and isotopic ratios and would then enter orbit, making remote sensing measurements of the planet's atmosphere, interior, magnetic field, and rings, as well as multiple flybys of the larger uranian satellites.
- **Venus Climate Mission:** This mission is designed to address science objectives concerning the Venus atmosphere, including carbon-dioxide greenhouse effects, dynamics and variability, surface-atmosphere exchange, and origin. The mission architecture includes a carrier spacecraft, a gondola and balloon system, a mini-probe, and two dropsondes.

The survey concludes that the top-priority large flagship mission for the coming decade would be MAX-C, which will begin the NASA-ESA Sample Return campaign – one that would not be completed into the decade beyond 2022. However, MAX-C, a joint ESA-NASA mission, was cancelled. In its place, NASA is developing MARS 2020, a rover that will conduct in-situ scientific studies and core, collect, and cache (store) geological samples for a future yet-to-be determined sample return mission to Earth.[39] The second

[37] NASA FY16 Budget Request. Pg. PS-32 <http://www.nasa.gov/sites/default/files/files/NASA_FY_2016_Budget_Estimates.pdf>

[38] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. Pg. 16-17 <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[39] NASA MARS 2020 website <http://mars.jpl.nasa.gov/mars2020/mission/overview/>

highest priority Flagship mission for the decade 2013-2022 is the Jupiter Europa Orbiter (JEO).

The Committee met, pursuant to call, at 10:01 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

Chairman SMITH. The Committee on Science, Space, and Technology will come to order.

Without objection, the Chair is authorized to declare recesses of the Committee at any time.

Welcome to today's hearing entitled "Exploration of the Solar System: From Mercury to Pluto and Beyond." I'll now recognize myself for an opening statement and then the Ranking Member.

The exploration of our universe captures Americans' interests, inspires us to pursue extraordinary goals, and keeps us on the forefront of scientific achievement. It also is what NASA was created to do.

Since 1958, NASA has led the world in space exploration with a long list of firsts: NASA built, launched, and operated the first spacecraft to encounter another planet, the first spacecraft to leave our solar system, and the first spacecraft to take humans to the moon.

Earlier this month, the New Horizons spacecraft achieved another American first by being the first spacecraft to reach Pluto. The photos and data sent back to Earth continue to capture the imagination of people around the world. These pictures show mountains of water ice, caverns deeper than the Grand Canyon, and evidence of geologic activity. And while we may not resolve debates about Pluto's planetary status today, at least one thing is for certain: Pluto has a heart. And this is just the beginning. It will take up to 16 months for all of the data from the Pluto system flyby to be downloaded.

NASA, the Southwest Research Institute, the Applied Physics Laboratory, and the New Horizons team deserve our appreciation for the successful mission to Pluto.

NASA also has ongoing missions to explore Mars, Jupiter, Saturn, and the asteroid belt. The Dawn mission to Ceres and Vesta continues to transmit impressive images and important science. Juno is on its way to Jupiter, scheduled to arrive next year, and pave the way for a future mission to Europa. These missions are the result of investments made a decade ago or longer.

It is crucial that NASA continue to explore our solar system. Planetary science teaches us about how our solar system works and provides clues about how it was formed. Planetary missions discover the locations of minerals and potential water sources on asteroids, comets, moons, and planets that could be used on human missions or extracted for use here on Earth.

Space exploration also inspires the next generation of young people to pursue careers in science, technology, engineering, and math. Today, young students across the country are reading about New Horizons, looking at photographs of Pluto, and are excited about one day exploring the cosmos themselves and making new discoveries.

Unfortunately, the Obama Administration's past and present proposed cuts to planetary science and exploration at NASA have made it clear these endeavors are not its priority. The Administra-

tion's fiscal year 2016 request cut funding for planetary science by $77 million from fiscal year 2015 levels.

Our Committee's NASA Authorization Act for fiscal year 2016 and 2017 restores these crucial funds to the science and exploration accounts. Funding levels requested by the Obama Administration would slow the rate at which we can develop, build, and launch new missions like New Horizons. This Committee's bill, and the funding levels approved in the House, would allow NASA to keep planetary missions like New Horizons on track. So I urge the Administration to support this commonsense, balanced, and reasonable approach, which will keep us on the forefront of space exploration and discovery.

I do thank our witnesses for being here today. We look forward to their testimony in just a minute.

[The prepared statement of Chairman Smith follows:]

PREPARED STATEMENT OF CHAIRMAN LAMAR S. SMITH

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I urge the Administration to support this common sense, balanced, and reasonable approach, which will keep us on the forefront of space exploration and discovery.
I thank the witnesses for being here today and look forward to hearing their testimony.

Chairman SMITH. And I'm going to yield the balance of my time to the gentleman from Texas, the Chairman of the Space Subcommittee, Bruce Babin.

Mr. BABIN. Thank you, Mr. Chairman.

Space exploration is a challenging endeavor that distinguishes the United States as a global leader, supports innovation and economic growth, and inspires the next generation to build, explore, and to discover.

The success of the Dawn mission to the asteroid Ceres and the New Horizons mission to Pluto demonstrate the national importance of space exploration and planetary science. Unfortunately, year after year, the Obama Administration has consistently cut funding and deprioritized NASA space exploration and planetary science. It is imperative that Congress continue to reject the Administration's cuts and support a well-funded exploration program.

My congratulations to Dr. Stern, NASA, and the New Horizons team on a successful mission to Pluto, and I thank all the witnesses for being here today and look forward to their testimony.

And I yield back the balance of my time, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
CHAIRMAN BRIAN BABIN

Space exploration is a challenging endeavor that distinguishes the United States as a global leader, supports innovation and economic growth, and inspires the next generation to build, explore, and discover.

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My congratulations to Dr. Stern, NASA, and the New Horizons team on a successful mission to Pluto. I thank the witnesses for being here today and look forward to their testimony.

Chairman SMITH. Thank you, Mr. Babin.

The gentlewoman from Maryland, Ms. Edwards, the Ranking Member today, is recognized for her opening statement.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and thank you to the witnesses. Good morning. And I appreciate being able to sit here on behalf of our Ranking Member, Congresswoman Eddie Bernice Johnson, who's on travel out of the country today with the President.

I want to join the Chairman in welcoming our witnesses in today's hearing. And we have such a distinguished panel so I truly do look forward to your testimony.

I believe we live in rather extraordinary times. We could see from the successful flyby of Pluto just two weeks ago and the announcement last week that an Earthlike planet had been discovered in the habitable zone of another star's solar system are just the most recent examples of the tremendous accomplishments that

have been made in planetary science and space exploration in recent years.

And it's quite notable that all of the solar system exploration missions that NASA has undertaken over the past half-century have raised as many exciting new research questions as they've answered. That is the nature of space exploration and it's why it's so important for this nation to continue to support it.

The New Horizons mission to Pluto is also a reminder of how challenging solar system missions really are. The nine-year flight to Pluto was preceded by years of design and engineering work to produce the spacecraft and instruments and the trajectory that made New Horizons a success.

I do want to salute the entire New Horizons team for their dedication and hard work over these many years and I'm sure that Dr. Stern will have much more to stay about the work that went into making the mission a success, but I also want to acknowledge and take note of the significant role played by Dr. Tom Krimigis and the Maryland-based Johns Hopkins Applied Physics Laboratory. You can tell we're very proud of APL and the development and execution of the New Horizons spacecraft and mission. They and the entire Pluto mission team can take pride in what has been accomplished.

Mr. Chairman, the Nation is making great progress in the exploration of our solar system. However, that progress has been made possible in large part by the investments in technology development that our predecessors had the foresight to fund. Frankly, it's now our turn as Members of Congress to show the same vision and I hope we will, by the time this year's funding battles get resolved, show that kind of commitment. We owe it to the dedicated scientists and engineers represented here today to do that.

Yet progress in solar system exploration is not just a question of funding. Those funds will need to be invested judiciously to ensure that NASA has the right technological capabilities in the years ahead. In addition, there will need to be clear and thoughtful prioritization of research objectives because there really is an embarrassment of riches when it comes to exciting new potential mission concepts. That's where the Decadal Surveys of the National Academies can continue to play a very useful role.

As Members of Congress, we all may have our own favorite destinations and missions, but it's important that the scientific community be at the forefront to determine priorities that address the most compelling scientific questions while ensuring that the Planetary Science program remains an appropriate balance across research fields. In the meantime, today's hearing is a wonderful opportunity to hear about some of the exciting results from missions now underway, as well as those being contemplated, and I truly cannot wait to hear from our witnesses.

And I would say just in closing a reminder to us that this work, as you all have described, is difficult, it's complex, and the last thing that you need are Members of Congress meddling in the scientific work. And so I look forward to hearing from you about what is going on now and what the prospects are. And I would like us as Members of Congress to step aside, make sure that we provide you the resources that you need, and expect that we may not know

the value of that for 50 years in the running. And I am indeed okay with that.

Thank you, and I yield.

[The prepared statement of Ms. Edwards follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE RANKING MINORITY MEMBER DONNA F. EDWARDS

Good morning. I want to join the Chairman in welcoming our witnesses to today's hearing. We have a distinguished panel, and I look forward to your testimony.

Mr. Chairman, we live in extraordinary times. The successful flyby of Pluto just two weeks ago and the announcement last week that an Earth-like planet had been discovered in the ″habitable zone″ of another star's solar system are just the most recent examples of the tremendous accomplishments that have been made in planetary science and space exploration in recent years.

And it's notable that all of the solar system exploration missions that NASA has undertaken over the past half-century have raised as many exciting new research questions as they have answered. That is the nature of space exploration, and why it is so important for this nation to continue to support it.

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I want to salute the entire New Horizons team for their dedication and hard work over those many years.

I'm sure Dr. Stern will have more to say about the work that went into making the mission a success, but I would like to note the significant role played by Dr. Tom Krimigis and the Maryland-based Johns Hopkins Applied Physics Laboratory in the development and execution of the New Horizons spacecraft and mission. They and the entire Pluto mission team can take pride in what has been accomplished.

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In the meantime, today's hearing is a wonderful opportunity to hear about some of the exciting results from missions now underway as well as those being contemplated, and I can't wait to hear from our witnesses.

Thank you, and I yield back.

Chairman SMITH. Thank you, Ms. Edwards.

And let me introduce our panel today. Our first witness is Dr. John Grunsfeld, Associate Administrator for the Science Mission Directorate at NASA. Prior to his appointment as Administrator, Dr. Grunsfeld was Deputy Director of the Space Telescope Science Institute where he managed science programs for the Hubble Space Telescope and James Webb Space Telescope as well. Dr. Grunsfeld also has served as NASA Chief Scientist, Chief of the Computer Support Branch in NASA's Astronaut Office, and Chief of the Extravehicular Activity Branch.

Dr. Grunsfeld has flown aboard five space shuttle flights, including the Atlantis, Discovery, and Columbia logging over 58 days in space and more than 58 hours of spacewalk time. He is the recipient of many awards, including the NASA Constellation Award.

Dr. Grunsfeld earned his bachelor of science degree in physics from MIT, his master's of science degree in physics from the University of Chicago, and his Ph.D. in physics from the University of Chicago.

Dr. Alan Stern, our next witness, is the Principal Investigator for the New Horizons mission at the Southwest Research Institute, which has a facility in my hometown, San Antonio, Texas, and in Boulder, Colorado. Before working at the Institute, Dr. Stern was Associate Administrator for the Science Mission Directorate at NASA. He also served on the Board of Directors of the Challenger Center for Space Science Education and was Director of the Florida Space Institute and Chief Scientist and Mission Architect for American Express.

Among other accomplishments, Dr. Stern has been awarded the von Braun Aerospace Achievement Award of the National Space Society and Smithsonian magazine's American Ingenuity Award.

Dr. Stern holds two bachelor's degrees in physics and astronomy and master of science degrees in planetary atmospheres and aerospace engineering from the University of Texas at Austin. He has a Ph.D. in astrophysics and planetary science from the University of Colorado at Boulder.

Our third witness today is Dr. Christopher Russell, Principal Investigator for the Dawn mission and Professor of Geophysics and Planetary Physics at the University Of California Los Angeles. Dr. Russell is also Principal Investigator of the Magnetic Fields Investigation on the Magnetospheric and Multiscale Mission and Lead Investigator for the Magnetometer for the InSight Mars lander.

Dr. Russell has received the American Geophysical Union's Macelwane and Fleming Medals and COSPAR's Science Award and even has an asteroid named after him, Asteroid 21459, Chris Russell. At least I am jealous of that. You too?

Dr. Russell earned his bachelor of science degree from the University of Toronto and his Ph.D. from the University of California Los Angeles. He has published over 1,500 scientific papers, receiving over 44,000 citations.

Our next witness, Dr. Robert Pappalardo, is a Study Scientist for the Europa Mission Concept at NASA's Jet Propulsion Laboratory. He has previously served as the Project Scientist for the Cassini Equinox Mission at Saturn and is Study Scientist for Jupiter Europa Orbiter. Prior to working for NASA, he was an Assistant Professor of Planetary Sciences in the Astrophysical and Planetary Sciences Department at the University Of Colorado at Boulder. He also was an Affiliate Member of the Galileo Imaging Team where he worked to plan many observations of Jupiter's icy satellites.

He is the recipient of honors, including NASA's Exceptional Service Medal, the NASA Group Achievement Award, and the JPL Mariner Award.

He received his bachelor of arts in the geological sciences from Cornell University and his Ph.D. in geology from Arizona State University.

Our final witness today is Dr. Robert Braun, David and Andrew Lewis Professor of Space Technology at the Georgia Institute of Technology. Dr. Braun is also the Founding Director of the Georgia Tech Center for Space Technology and Research. Dr. Braun has served as NASA Chief Technologist. He also has served as a member of the Mars Pathfinder Design and Landing Operations Team and as part of the development teams for the Mars Microprobe, Mars Sample Return, and Mars Surveyor 2001 projects. He is the Editor-in-Chief of the AIAA Journal of Spacecraft and Rockets and is the author or coauthor of over 275 technical publications.

He is the recipient of many awards, including the 1999 AIAA Lawrence Sperry Award and two NASA Exceptional Achievement Medals.

Dr. Braun received his bachelor's degree in aerospace engineering from Penn State, his master's degree in aeronautics from George Washington University, and his Ph.D. in aeronautics and astronautics from Stanford.

As the Members can see, this is an exceptionally qualified panel of experts. They have wonderful backgrounds, wonderful expertise in all kind of areas, and we welcome you all today.

And, Dr. Grunsfeld, we'll begin with you.

TESTIMONY OF DR. JOHN GRUNSFELD, ASSOCIATE ADMINISTRATOR, SCIENCE MISSION DIRECTORATE, NASA

Dr. GRUNSFELD. Well, thank you very much for the opportunity to appear today, and I want to say right off the bat that you are all team members in this great enterprise.

For of the last 50 years, we have been on an epic journey of discovery, true exploration, and the results have been extraordinary. Two weeks ago, NASA's New Horizons spacecraft made an historic flyby through the Pluto system. This capstone event celebrates the fact that in the last 50 years the United States has been the first to visit each of the planets, and now the dwarf planet Pluto in our solar system.

Our NASA Planetary Science program leads the world in the exploration of the solar system, and I'd like to take you on a short journey through that solar system.

[Slide.]

This is an image. Many of us forget that the sun is the center of our solar system. From yesterday from our Solar Dynamics Observatory, Mercury, from the MESSENGER spacecraft, we discovered a new world through the MESSENGER mission.

[Slide.]

Venus from the Magellan spacecraft, 1990, launched from the space shuttle.

[Slide.]

The Earth, the Earth is in fact a planet from our new Discover mission a million miles from Earth.

[Slide.]

Mars, I had to get a Hubble Space Telescope picture in there taken from the Hubble.

[Slide.]

Ceres in the main asteroid belt, the largest dwarf planet in the asteroid belt from the Dawn mission. You'll hear about that.

[Slide.]

Jupiter from Galileo arrived 1995, also launched from the space shuttle.

[Slide.]

Saturn from Cassini still exploring.

[Slide.]

Uranus from Voyager 2.

[Slide.]

Neptune from Voyager 2.

[Slide.]

And the capstone Pluto, as we've just seen from the New Horizons July 14. And as you can see from this last image, Pluto has not disappointed the scientific community or the public.

In April, the NASA MESSENGER mission hit the surface of Mercury as planned after a stellar four-year mission. A key science finding of the mission is compelling evidence that Mercury harbors water ice and other volatile materials in its permanently shadowed craters.

On Mars we have the Curiosity rover. It's already shown us that Mars is a highly evolved, dynamic planet that once could have supported microbial life and has the potential to support human life in the future.

Future missions to Mars include the InSight mission, which will launch in 2016, providing our first look into the deep interior of Mars and the NASA Mars 2020 Rover, which will be the first to acquire geologic samples for potential future return.

The Dawn mission, as you'll hear, is currently studying the dwarf planet Ceres, which is the largest object in the main asteroid belt. Dawn has the distinction of being the first spacecraft to orbit a dwarf planet.

Asteroids and other small bodies continue to be objects of importance for NASA to study, and we're currently developing a very ambitious mission for a robotic asteroid rendezvous and sample return dubbed OSIRIS–REx, which is planned to launch next year.

On the way to Jupiter, as you've heard, is our Juno mission, which will arrive next year, the biggest planet in our solar system. The mission will investigate our largest planet's composition, atmosphere, belts, and magnetic field. Jupiter is host to a collection of amazing moons, several of which are larger than our own moon. Europa, which you'll hear about, may harbor a salty ocean underneath a thick crust of ice with the potential to harbor life. NASA is working on a mission that will send a highly capable spacecraft to investigate this fascinating world.

At Saturn, Cassini spacecraft recently observed the moon Enceladus emitting sheets of water or plumes from features on the surface. These plumes may come from subsurface lakes that could represent safe harbors for microbial life. In 2017 the Cassini mission will be sent on a brand-new mission. As it runs out of fuel, it will orbit Saturn and then enter the Saturnian atmosphere, a dramatic and fitting end for a transformative planetary explorer.

While we have no current plans to visit Uranus and Neptune, the James Webb Space Telescope, which will launch in October

2018, promises to provide extraordinary science by observing these giant ice planets in unparalleled spectroscopic detail.

And still further out, Voyager 1 and 2 continue to operate as part of Voyager's Interstellar Mission. The two Voyagers hold records as the longest-operating and the most distant spacecraft ever built by humankind.

The United States has been the first nation to successfully reach every planet from Mercury to Pluto with the space probe but our study of the solar system does not stop at Voyagers or New Horizons. We continue to seek fundamental science questions, including whether we are alone in the universe. NASA will probe deeper into this question by studying solar systems around other stars, exoplanets, using Hubble, Spitzer, Kepler, and launching in 2017 the Transiting Exoplanet Survey Satellite.

This great journey into the unknown continues and there is still much to be learned. With your support, our future missions will advance along this path of exploration, discovery, and innovation for generations to come.

Thank you.

[The prepared statement of Mr. Grunsfeld follows:]

Statement of
Dr. John Grunsfeld
Associate Administrator, Science Mission Directorate
National Aeronautics and Space Administration

before the

Committee on Science, Space and Technology
U.S. House of Representatives

Chairman Smith, Ranking Member Johnson and Members of the Committee, thank you for the opportunity to appear today to discuss recent discoveries in the exploration of our solar system as well as the future of NASA's Planetary Science program and our missions. For decades, NASA has extended US leadership in planetary exploration with increasingly capable missions and has produced a series of exciting achievements in planetary science.

Two weeks ago, on July 14th, NASA's New Horizons spacecraft made an historic flyby through the Pluto system, providing high-resolution images and other science observations from this first visit to Pluto and its moons. This capstone event celebrates the fact that in the last 50 years the U.S. has been the first to visit each of the planets, and now the dwarf planet Pluto in our solar system. We now have close-up views of this enigmatic object and its moons that are already testing our ideas about the formation of our solar system. We have known about Pluto now for over 85 years, since the discovery by American astronomer Clyde Tombaugh, but even observations with the venerable Hubble Space Telescope revealed only rough details. Like the explorers of the classic era, the NASA New Horizons mission captured previously unseen vistas allowing us to make the first maps of Pluto and its moons. Now, as New Horizons speeds off beyond Pluto, it is entering a new realm of the solar system, the Kuiper Belt. I look forward to Dr. Stern's testimony in which he will provide additional details about the New Horizons mission.

From the sun, which provides the warmth and energy that allows the Earth to be a habitable planet, to Mercury, Venus, the Earth, Mars, the main asteroid belt, Jupiter, Saturn, Uranus, Neptune, Pluto, and even into interstellar space, NASA space probes have been humanity's pathfinders and explorers in the depths of our solar system. We study the planets in our solar system to answer fundamental question about where we come from, how the solar system came to be, and in the search for life beyond the Earth. Space exploration is difficult, requiring our best and brightest engineers and scientists to succeed, and when we develop innovative probes to explore the solar system, we invent technologies which improve our lives here on planet Earth.

We continue to study our sun, the central driver of much of what we see in the solar system. Our STEREO spacecraft orbit the sun providing unmatched views, the Solar Dynamics Observatory continues to return amazing detail on a near real-time basis, the

Voyager 1 spacecraft continues to provide us with data from interstellar space and Voyager 2 from a far region of our solar system, and we are preparing to launch the Solar Probe Plus and Solar Orbiter in 2018.

NASA's MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft has changed our understanding of the planet Mercury. Although Mercury is one of Earth's nearest planetary neighbors, little was known about the planet prior to the MESSENGER mission. Among its many accomplishments after entering Mercury's orbit in 2011, the MESSENGER mission determined Mercury's surface composition, revealed its geological history and confirmed its internal magnetic field is offset from the planet's center. One key science finding of the mission provided compelling support for the long-held hypothesis that Mercury harbors abundant water ice and other volatile materials in its permanently shadowed polar craters. Data indicated the ice in Mercury's polar regions, if spread over an area the size of Washington, D.C., would be more than two miles thick. For the first time, scientists began seeing clearly a chapter in the story of how the inner planets, including Earth, acquired water and some of the chemical building blocks for life. A dark layer covering most of the water ice deposits supports the theory that organic compounds, as well as water, were delivered from the outer solar system to the inner planets and their delivery may have led to prebiotic chemical synthesis and thus to life on Earth.

Originally planned to orbit Mercury for one year, the mission exceeded all expectations, lasting for over four years and acquiring extensive datasets with its seven scientific instruments and radio science investigation. On April 30th, however, the spacecraft expended all of its fuel and impacted Mercury's surface. Given the incredible science returns thus far, we look forward to future discoveries through analysis of the data and images gathered by the MESSENGER mission during its lifetime.

At Mars, we have several missions in operation with more in development. The current Mars portfolio includes the *Curiosity* and *Opportunity* rovers, the Mars Reconnaissance Orbiter, the Mars Odyssey orbiter, and our collaboration with the European Space Agency's (ESA) Mars Express orbiter. These missions have already shown us a highly evolved dynamic planet that once could have supported microbial life and has the potential to support humans in the future. The mission portfolio also includes the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter, which arrived at the Red Planet last year to study the history of Mars' atmosphere and climate, liquid water and planetary habitability. Building on the success of these operating missions, NASA's Planetary Science program will continue its strategic, multi-mission approach to thoroughly investigating Mars.

Future missions to Mars include the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission, which will launch and land in 2016, providing our first look into the deep interior of Mars; participation on ESA's 2016 and 2018 ExoMars missions; and the new NASA Mars rover planned for launch in 2020. In particular, the Mars 2020 rover will carry seven instruments to conduct geological assessments of the rover's landing site, determine the potential habitability of the

environment, directly search for signs of ancient Martian life and for the first time, collect high-grade samples for potential future return to Earth. Furthermore, the Mars 2020 mission will help advance our knowledge of how we may achieve the ultimate goal of landing humans on Mars. The Mars 2020 heat shield will include instruments that collect data during descent through the Martian atmosphere to inform designers of future landing systems. Once on the surface, the rover will also carry an experimental payload to demonstrate technology to process carbon dioxide from the atmosphere to produce oxygen – a method that could one day be used to produce oxygen for rocket propellant.

Beyond Mars is the main asteroid belt; there NASA's Dawn mission is currently studying the dwarf planet, Ceres, which is the largest object in the main asteroid belt. Previously, the Dawn mission explored the giant asteroid Vesta for 14 months from 2011 to 2012. Dawn has the distinction of being the first spacecraft to orbit a dwarf planet and the only spacecraft to orbit two extraterrestrial targets.

After arriving at Ceres in March of this year, Dawn began returning a wealth of photographs and other scientific measurements to help characterize and investigate the dwarf planet. Most notably, Dawn has captured a sequence of images that showcase a group of bright spots on Ceres, which scientists have concluded are caused by the reflection of sunlight by material on the surface. Dawn's visible and infrared mapping spectrometer allows scientists to identify specific minerals present on Ceres by looking at how light is reflected. Each mineral reflects the range of visible and infrared-light wavelengths in a unique way, and this signature helps scientists determine the components of Ceres. As the spacecraft continues to send back additional images and data, scientists will learn more about the mysterious bright spots.

In addition to the bright spots, Dawn's view from its present altitude has included a wide range of other intriguing sights, including craters, canyons and mountainous regions. There is also ample evidence of past activity on the surface, including flows, landslides and collapsed structures. With two very successful mapping campaigns complete, Dawn's next priority is to work its way down through Ceres' gravitational field to maneuver to a circular orbit three times as close to the dwarf planet as it is now, to an altitude of about 900 miles (less than 1,500 kilometers) for additional investigations. I look forward to Dr. Russell's testimony which will provide additional details about the Dawn mission.

As demonstrated by Dawn's extensive study of Vesta, asteroids and other small bodies continue to be objects of importance for NASA to study. Examination of these objects allows scientists to investigate how planets formed and how life began and improves our understanding of asteroids that could impact Earth. For example, NASA is currently developing a robotic asteroid rendezvous and sample return mission, dubbed OSIRIS-REx (for Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer), which is planned to launch next year. The first U.S. mission of its kind, OSIRIS-REx will approach the near-Earth Asteroid 1999 RQ36 (Bennu), map the asteroid, and collect a sample of as much as 1.2 kg for return to Earth in 2023. In addition, NASA restarted the Wide-field Infrared Survey Explorer (now called

NEOWISE) to collect data on near-Earth objects (NEO) over a three year study – which will end next year – and provide us the clearest picture yet of the NEOs that pose impact hazards to our planet. Currently, NEOWISE has made more than 264,000 infrared measurements of 13,522 solar system objects, including 348 NEOs and 66 comets.

SMD's Near Earth Object (NEO) Program is also using its extensive ground and space observatory network to help find suitable asteroid candidates for NASA's Asteroid Redirect Mission (ARM) – a robotic mission aimed to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the moon for astronauts to explore. While not specifically a science mission, ARM is a cost effective mission in the mid-2020s, which complements well the learning on the International Space Station and provides cross-directorate research and technology development through NASA's Human Exploration and Operations, Science and Space Technology Mission Directorates. In particular, potential candidates for ARM are just a subset of the population of near-Earth asteroids that the Science Mission Directorate's NEO Program seeks to find in its primary mission. As our surveys find asteroids that might make good candidates for ARM, we further characterize the object for our own NEO Program interests as well as for potential destinations for robotic or human spaceflight missions.

On the way to Jupiter is our Juno mission, which will arrive next year at the biggest planet in our solar system. The mission will hopefully reveal our largest planet's composition; whether there exists a solid core; how deep Jupiter's atmospheric zones, belts, and other features penetrate; how far reaching and intense is its magnetic field; and how much water and ammonia exists in its atmosphere.

Jupiter is host to a collection of amazing moons, several of which are larger than our own moon. One of the most fascinating of Jupiter's moons is Europa, which is believed to harbor a salty ocean underneath a thick crust of ice. This enigmatic body holds the potential to harbor life in its ocean. NASA is working on a mission that will send a highly capable, radiation-tolerant spacecraft into a long, looping orbit around Jupiter to perform repeated close flybys of the giant planet's moon. The goal will be to conduct detailed reconnaissance of Europa and to answer the big question, "Is Europa habitable?"

Last year, NASA invited researchers to submit proposals for instruments to study Europa. Thirty-three were reviewed and nine were selected this past May for a mission that will launch in the mid-to-late 2020s. The payload of selected science instruments includes cameras and spectrometers to produce high-resolution images of Europa's surface and determine its composition, while an ice-penetrating radar will determine the thickness of the moon's icy shell and search for subsurface lakes similar to those beneath Antarctica. The mission also will carry a magnetometer to measure strength and direction of the moon's magnetic field, which will allow scientists to determine the depth and salinity of its ocean. A thermal instrument will scour Europa's frozen surface in search of recent eruptions of warmer water, while additional instruments will search for evidence of water and tiny particles in the Europa's thin atmosphere. I look forward to Dr. Pappalrdo's testimony which will provide additional details about our planned Europa mission.

Further out at Saturn, Cassini continues to bring us valuable discoveries in the Saturn system, providing what can only be described as some of the most vivid and captivating images ever taken in our solar system. Recently, the Cassini spacecraft observed the small moon Enceladus emitting sheets of water from features on the surface. These water plumes may well indicate that under the icy crust of Enceladus there are subsurface lakes, created by tidal heating. These subsurface lakes could represent safe harbors for microbial life. In 2017, the Cassini mission will be sent on a new mission, as it runs out of fuel, to orbit inside of the rings and plunge into the Saturnian atmosphere, taking data on the way in; a dramatic and fitting end for a transformative planetary explorer.

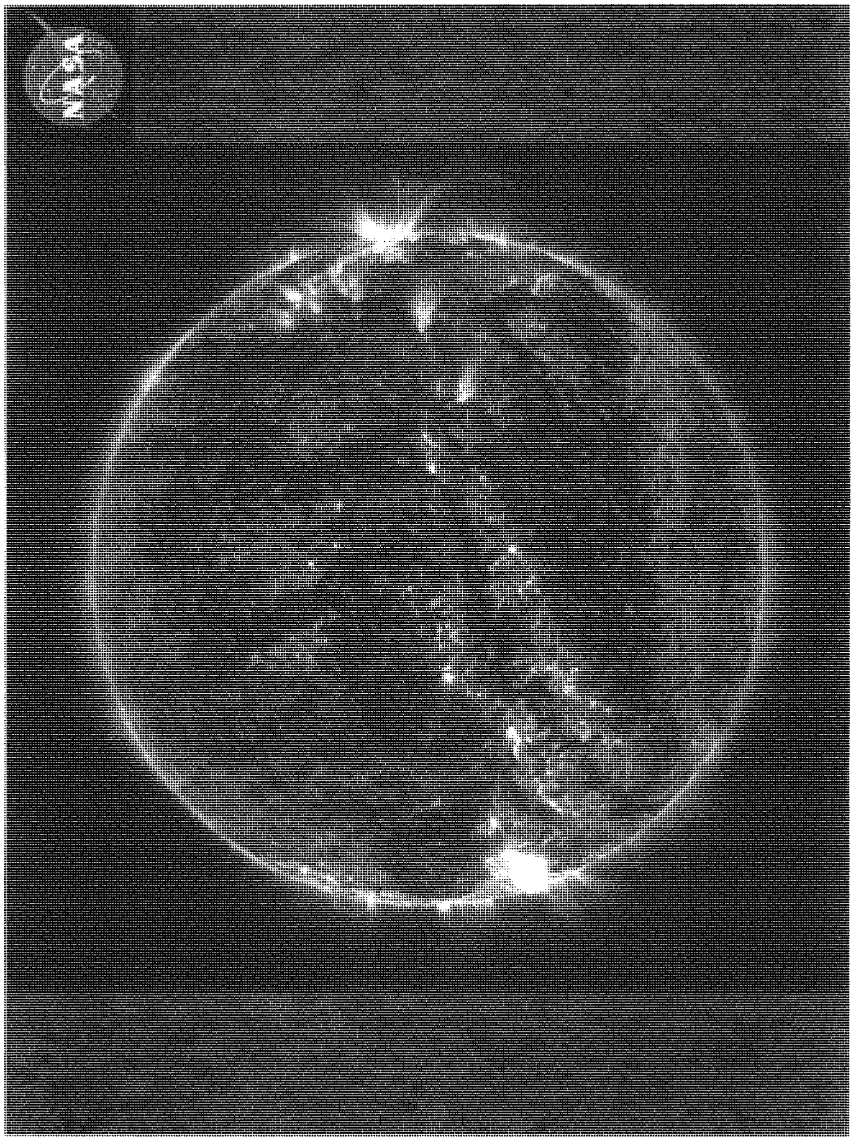
While we have no current plans for a revisit to Uranus and Neptune, following on the grand tour of Voyager 2 in the late 1980s, the James Webb Space Telescope promises to provide extraordinary science by observing these giant icy planets in unparalleled spectroscopic detail.

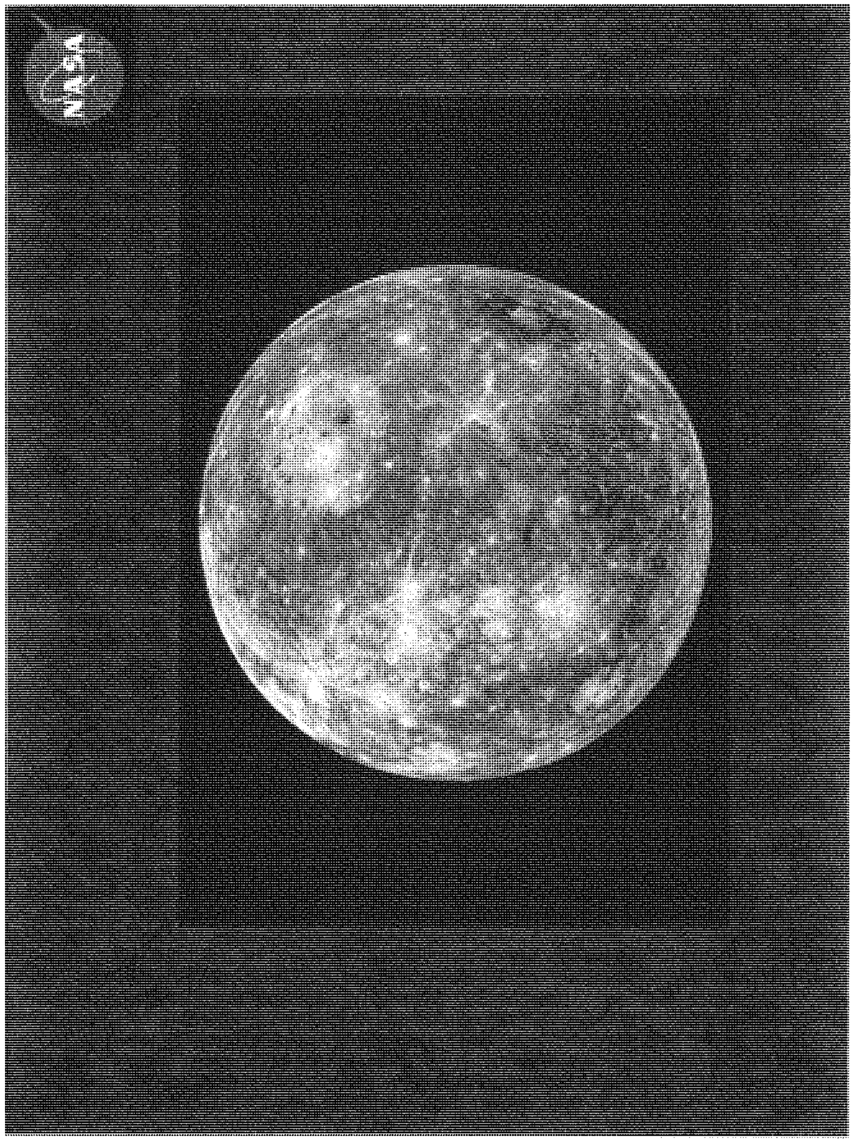
And while New Horizons has already provided exciting views of the dwarf planet Pluto and its moons, the mission will also venture deeper into the distant Kuiper Belt, initiating exploration of a relic of solar system formation that comprises many Pluto-like objects. These observations will be critical to our understanding of this distant and so far unexplored outer region of our solar system. And still further out, Voyager 1 and 2 continue to operate as part of the Voyager Interstellar Mission. These two aging, but still capable, explorers continue to study the outer heliosphere, the heliosheath and now the interstellar medium with plasma, energetic particle, magnetic field and plasma wave instruments. Among them, the two Voyagers hold records as the longest-operating and the most distant spacecraft ever built by humankind.

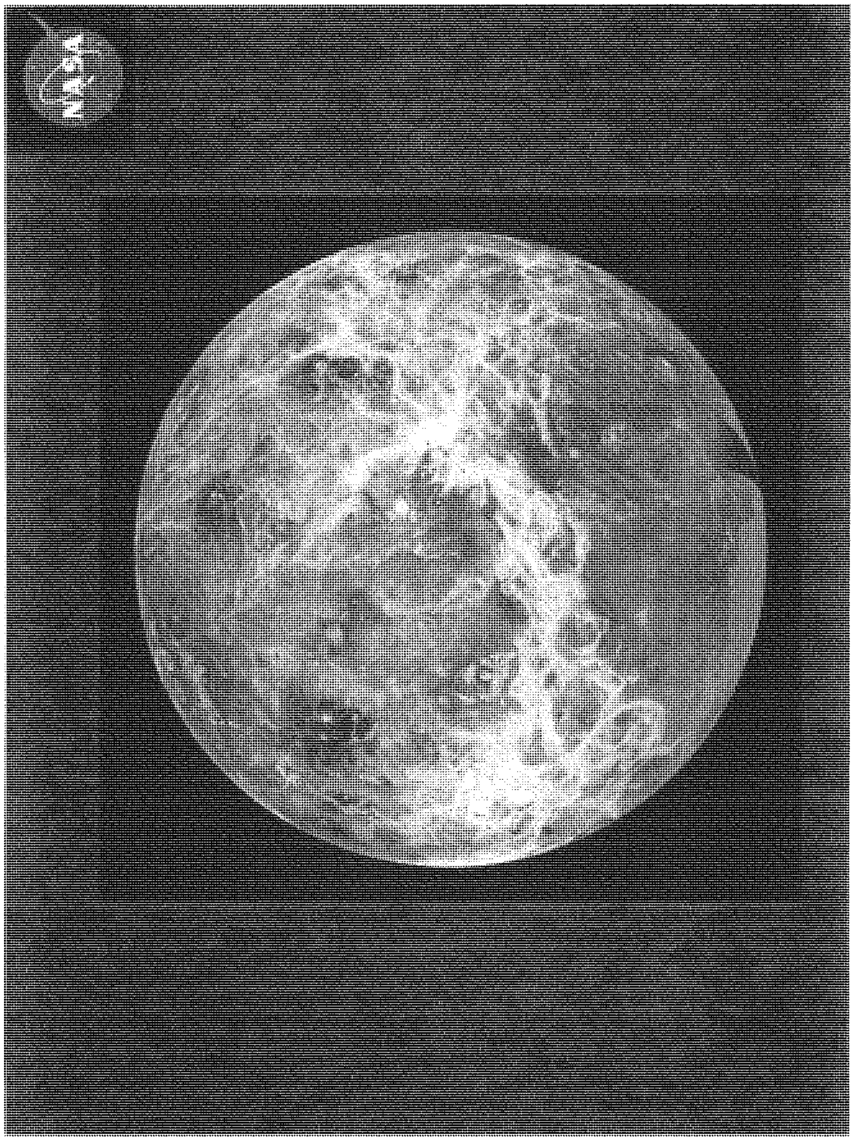
Conclusion

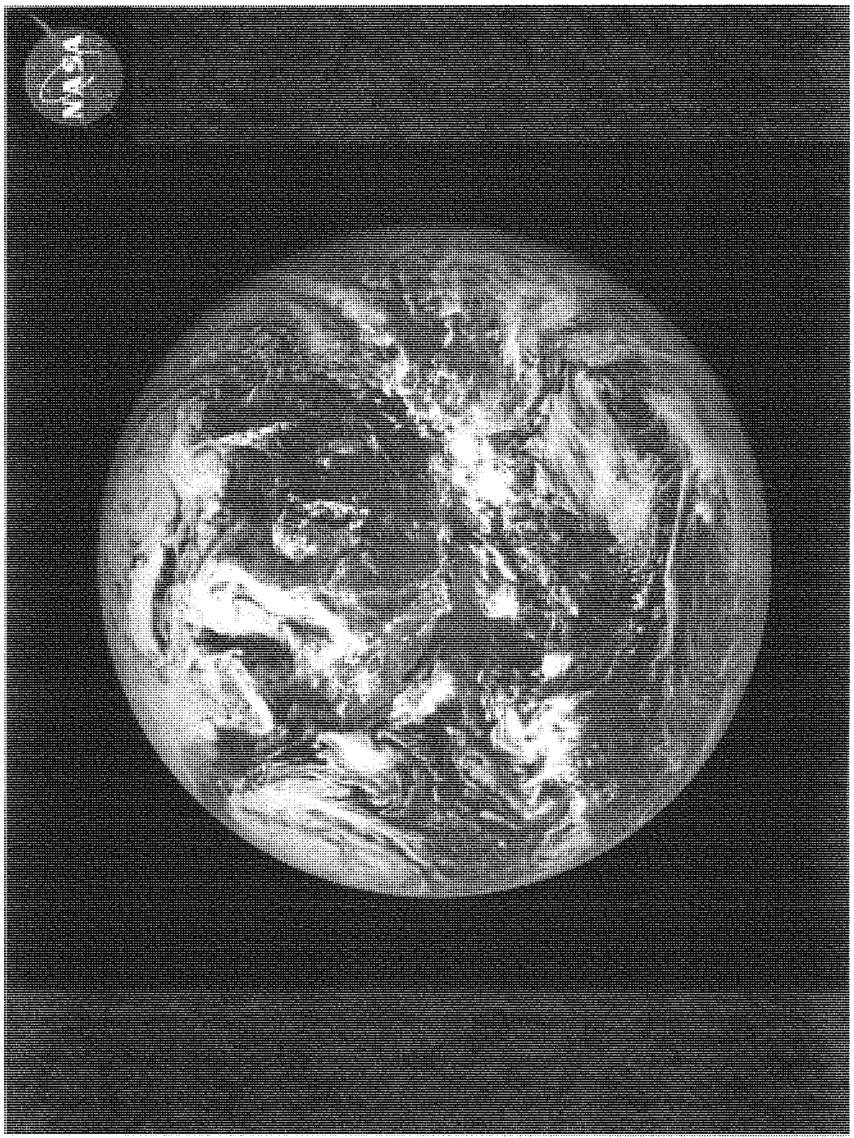
The United States has been the first nation successfully to reach every planet from Mercury to Pluto with a space probe, but our study of the solar system does not stop at the Voyagers or New Horizons. We continue to seek answers to fundamental science questions, including whether we are alone in the universe. NASA will probe deeper into this question by studying solar systems around *other* stars (exoplanets) using Hubble, Spitzer, Kepler, the Transiting Exoplanet Survey Satellite (TESS) that will launch in 2018, and ground-based telescopes. We eagerly await the James Webb Space Telescope and its potential to transform this field. This great journey into the unknown continues and there is still much to be learned. With your support, our future missions will advance along this path of exploration, discovery and innovation for generations to come.

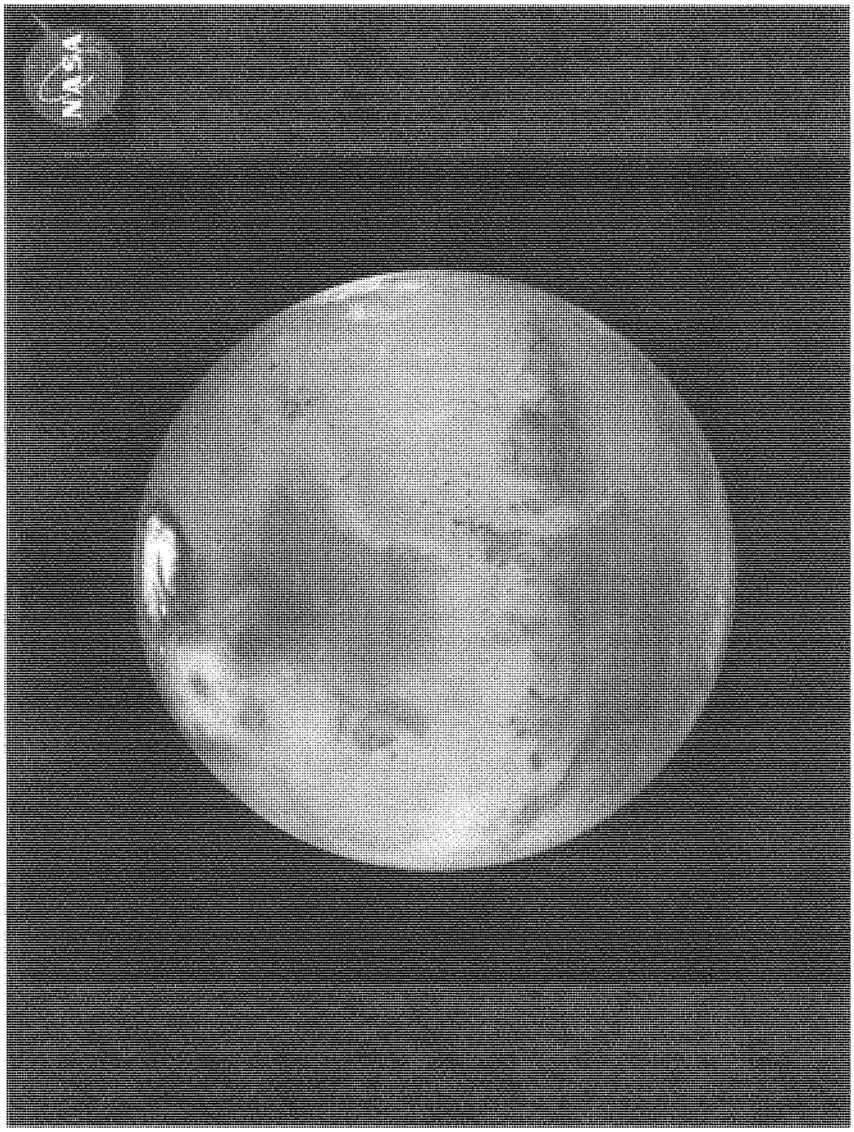
Again, thank you for the opportunity to testify today and I look forward to responding to any questions you may have.

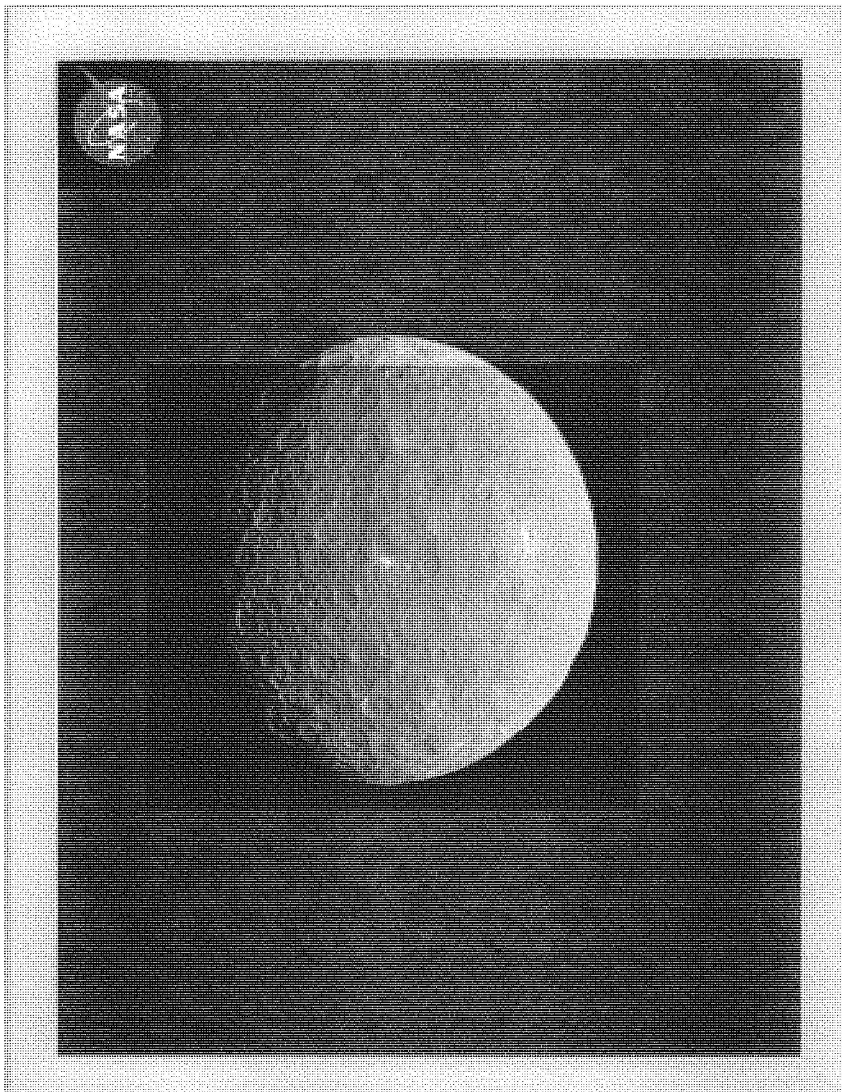


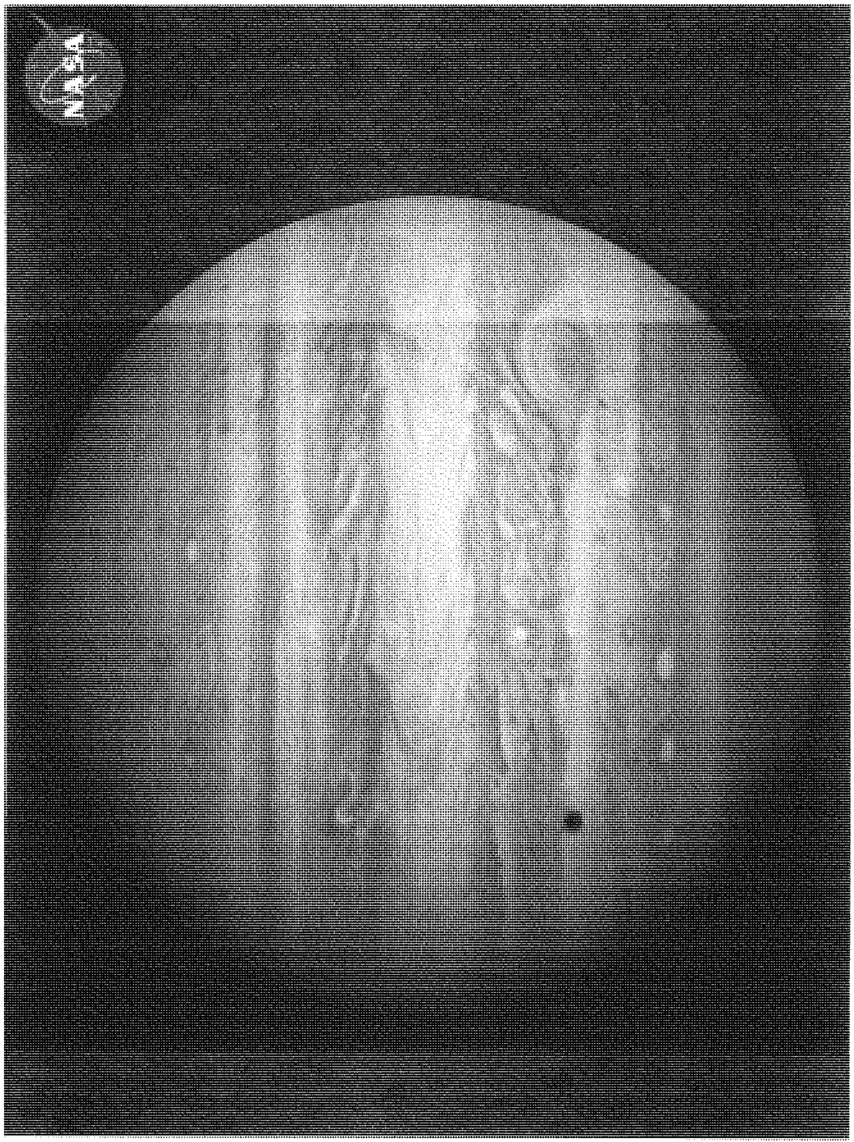








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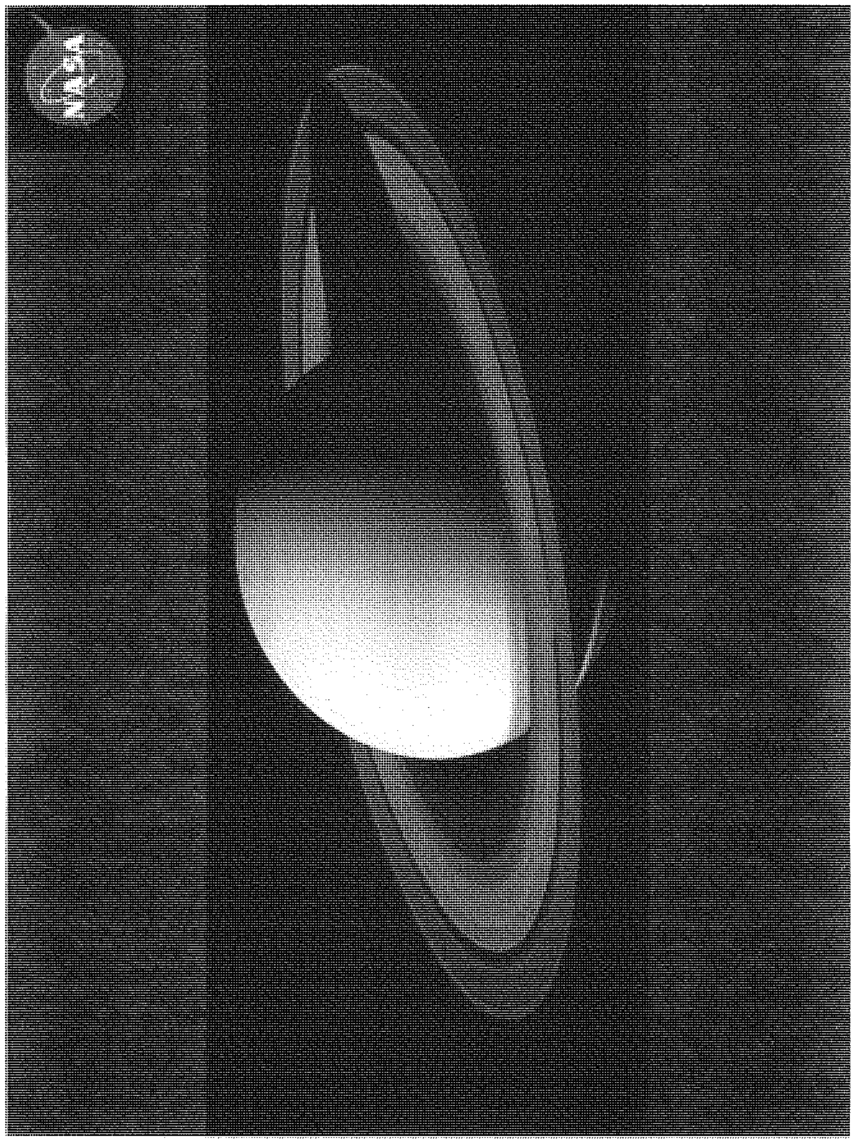
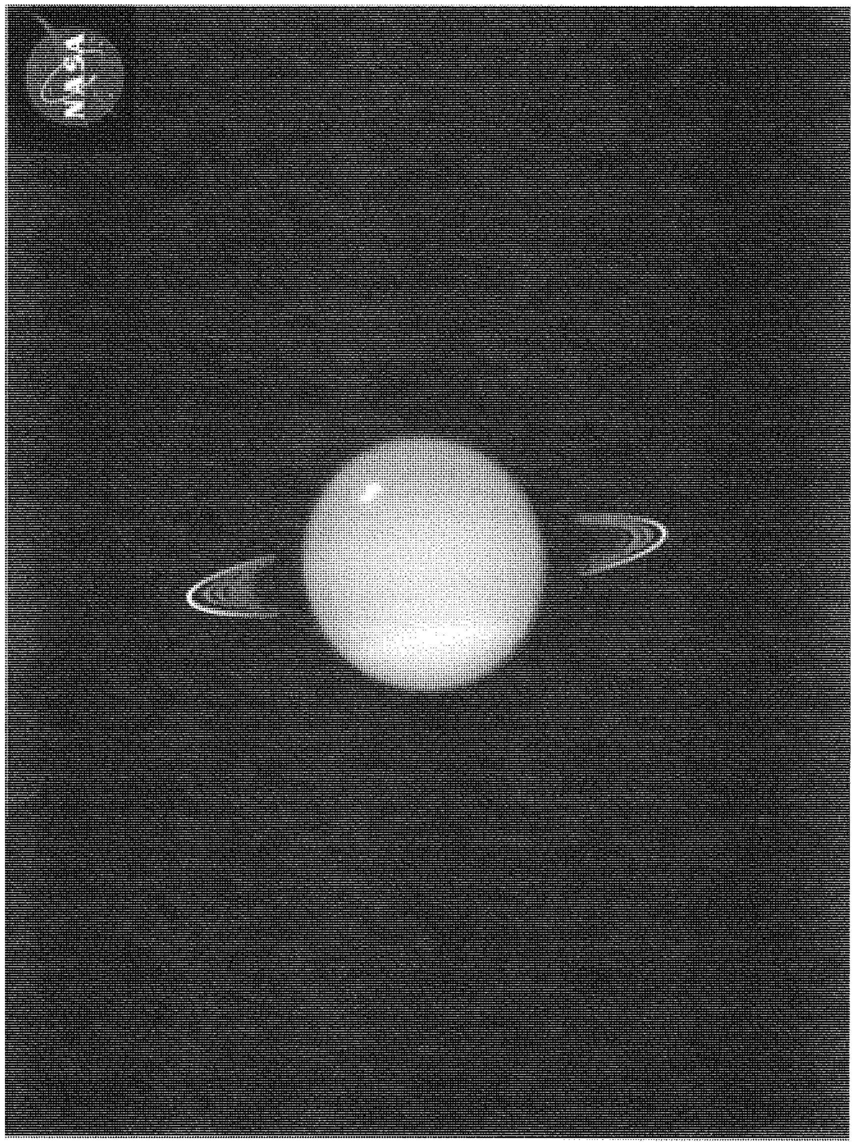
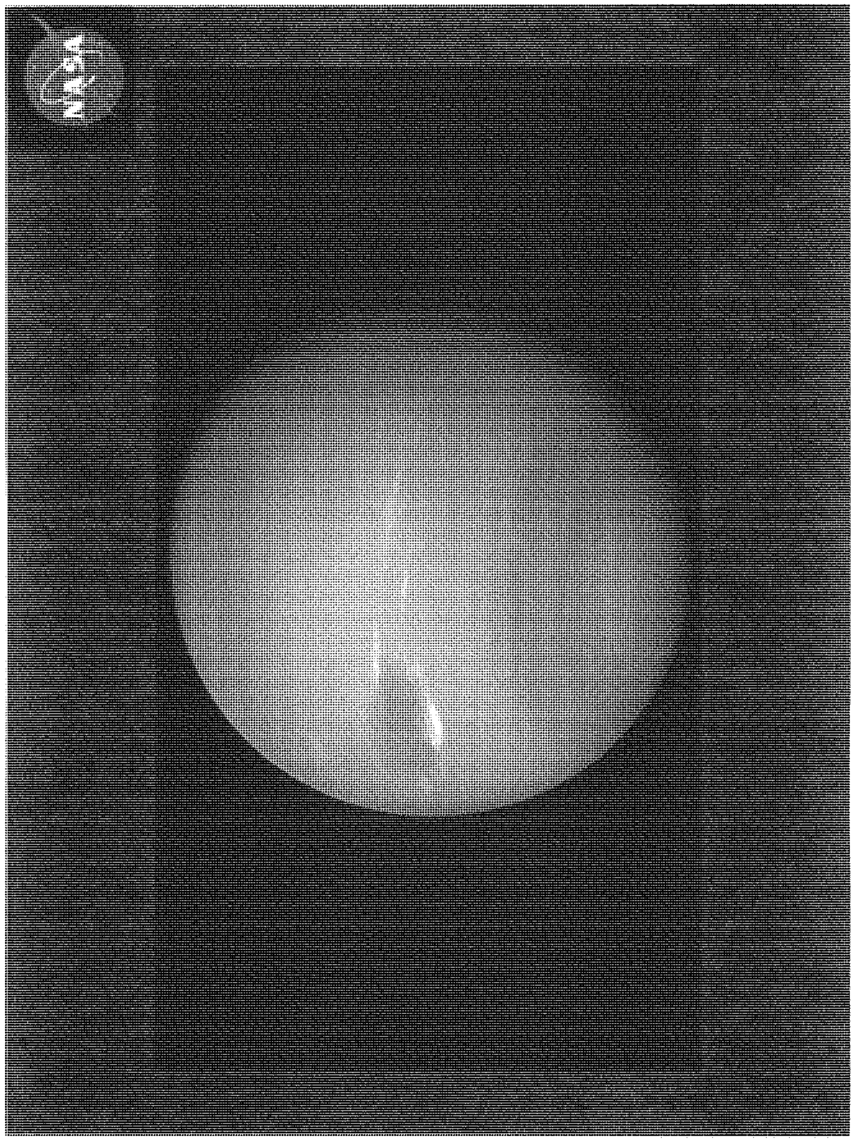
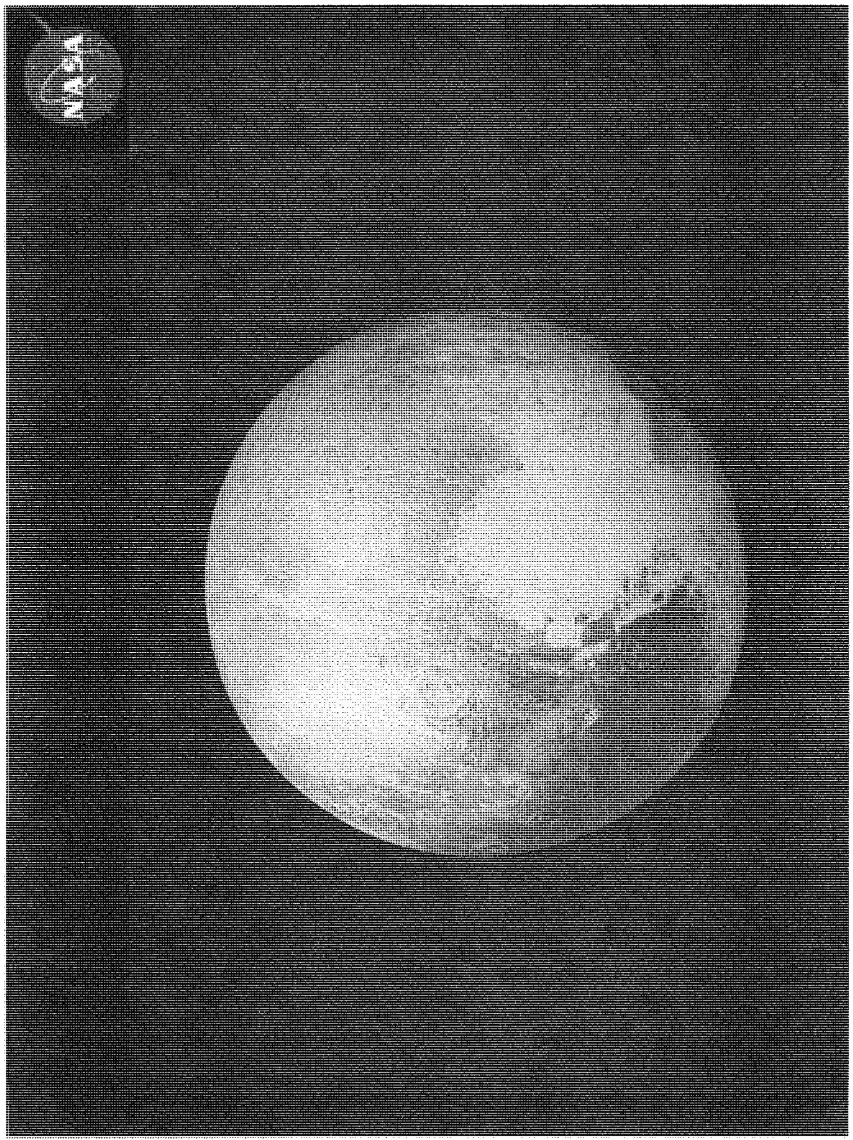
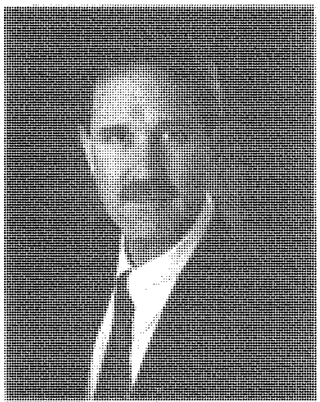








John M. Grunsfeld, Associate Administrator for the Science Mission Directorate



John M. Grunsfeld, Associate Administrator for the Science Mission Directorate
Credits: NASA/Bill Ingalls

John M. Grunsfeld was named Associate Administrator for the Science Mission Directorate at NASA Headquarters in Washington, D.C. in January 2012. He previously served as the Deputy Director of the Space Telescope Science Institute in Baltimore, managing the science program for the Hubble Space Telescope and the forthcoming James Webb Space Telescope. Grunsfeld's background includes research in high energy astrophysics, cosmic ray physics and in the emerging field of exoplanet studies with specific interest in future astronomical instrumentation.

Grunsfeld joined NASA's Astronaut Office in 1992. He is veteran of five space shuttle flights, and visited Hubble three times during these missions. He also performed eight spacewalks to service and upgrade the observatory. He logged more than 58 days in space on his shuttle missions, including 58 hours and 30 minutes of spacewalk time. Grunsfeld first flew to space aboard Endeavour in March 1995 on a mission that studied the far ultraviolet spectra of faint astronomical objects using the Astro-2 Observatory. His second flight was aboard Atlantis in January 1997. The mission docked with the Russian space station Mir, exchanged U.S. astronauts living aboard the outpost, and performed scientific research using the Biorack payload. He also flew on Discovery in December 1999, Columbia in March 2002 and Atlantis in May 2009. This last flight

successfully serviced and upgraded the Hubble Space Telescope, during which he was lead spacewalker for Hubble servicing activities. In 2004 and 2005, he served as the commander and science officer on the backup crew for Expedition 13 to the International Space Station.

Grunsfeld graduated from the Massachusetts Institute of Technology in 1980 with a bachelor's degree in physics. He subsequently earned a master's degree and, in 1988, a doctorate in physics from the University of Chicago using a cosmic ray experiment on space shuttle Challenger for his doctoral thesis. From Chicago, he joined the faculty of the California Institute of Technology as a Senior Research Fellow in Physics, Mathematics and Astronomy.

Chairman SMITH. Thank you, Dr. Grunsfeld.
And, Dr. Stern.

TESTIMONY OF DR. ALAN STERN, PRINCIPAL INVESTIGATOR, NEW HORIZONS MISSION, SOUTHWEST RESEARCH INSTITUTE

Dr. STERN. Well, thank you very much. Thank you for the opportunity for New Horizons to appear today to discuss NASA's exploration of the Pluto system.

I'd like to start, if I may, by introducing Glen Fountain, who's our Project Manager, and several members of our team who came downtown. If they would stand up, I would appreciate it. Twenty-five hundred Americans worked to make us all proud and they are representatives of that team.

Well, if I can have the first time step in the view graph.

[Slide.]

Next one, there you go, there's a picture of our spacecraft and a cartoon drawing both on the left and of course our launch on an Atlas V back in 2006. I want to say just a little bit about this spacecraft. It only weighs about 1,000 pounds. It is an amazing testament to the technology developed in NASA. We didn't send two of these like in the grand days of Mariner and Pioneer and Voyager, one lone spacecraft across three billion miles of space. It carries seven scientific instruments so sophisticated that all seven combined weigh less than just the camera on the Cassini Saturn Orbiter. All seven together, when all operating, draw 28 watts, less than half a light bulb, and yet they represent thousands of times the power of the instrumentation built in the 1970s for Voyager.

If I can have the next time step.

[Slide.]

This is the epic journey that we just completed. We launched from Florida in January of 2006, the fastest spacecraft ever launched, nine hours to the orbit of the moon, about 10 times faster than Apollo, only 13 months to reach Jupiter. Compare that to 6–1/2 years for Galileo, 4–1/2 years for Cassini. At Jupiter, we conducted a very successful scientific flyby and flight test and hit the window to target us for a Pluto encounter this summer. Following the Jupiter flyby, we spent eight years crossing 2–1/2 billion miles of space to the farthest shore that humankind has ever explored.

Now, I have to say it took 26 years to go from the first of Mariner mission to Venus all the way to Neptune and it was another 26 years before we flew this mission. In 1990, the U.S. Postal Service issued a set of stamps commemorating the first missions to every planet. If I can have the next time step.

[Slide.]

The only one for Pluto they could come up with said "not yet explored." We flew one of those stamps on New Horizons to Pluto and two weeks ago today we canceled it. So we really did it. This is an amazing team of people. And if I can have the next view graph, let me show you the Pluto system.

[Slide.]

This is their first trip to a binary planet, Pluto on the left, its large moon Charon on the right for scale. The diameter of Charon

is almost precisely the diameter of the State of Texas, by the way. Pluto is about the diameter of the United States. And you can see they're very different. Charon has no atmosphere. It has no substantial volatiles on its surface. It's much darker and less reflective. It's not colored. How these two came to be is a mystery to us. Why they should have traveled together for so many billions of years and yet been so different is unknown, and that is part of the power and the attraction of planetary science because we are exploring the unknown.

Next time step, please.

[Slide.]

Well, this is Charon up close as seen by New Horizons. You can see it's a pretty battered world. It's covered in water, ice. It's got a strange, dark hole. You can see there that we informally call Mordor, large chasms. You've got to engage the public.

Large chasms and these craters are going to tell us a lot about the population of the Kuiper belt. Perhaps I can answer more questions about Charon later. Let me show you the star of the show. Next time step, please.

[Slide.]

This is Pluto in false color on the right and accurate color on the left. This is one amazing world and we really don't understand how a world of this complexity can have come to be and still be active today four billion years after its formation. We have a lot of work to do to understand this. I can show you some close-ups from the encounter. That's the next time step.

[Slide.]

Here are just two of many close-ups to come. These are already on the ground. Both of those scenes are about 250 miles across. On the left is the Discovery image that gave us evidence for nitrogen glaciers, perhaps liquids flowing under those glaciers on Pluto, 400 degrees below zero, absolutely amazing. And on the right——

Chairman SMITH. Dr. Stern, are these photos that no one has seen before? I understood we had a couple and these may be those.

Dr. STERN. These are—these all came down last week——

Chairman SMITH. Last week.

Dr. STERN. —and they had been released before, sir.

Chairman SMITH. Okay.

Dr. STERN. On the right is a mountain range which we informally have named for Tenzing Norgay. We often call Pluto the Everest of planetary exploration and we have named the two mountain ranges that we've discovered for Hillary and Norgay. These are about as tall as the Rockies.

We are continually surprised by the data that's coming down. There's now evidence for an internal ocean in Pluto and perhaps another at Charon, evidence for global change, evidence for atmospheric hazes, and many other wonders. I have to say, with only five percent of the data on the ground, we all feel like we need to fasten our seatbelts for the remaining 95 percent. This is quite a ride scientifically.

Now, if I can turn to the next view graph, I want to say that it was a tremendous public response to the flyby of Pluto.

[Slide.]

This is a scene from the Johns Hopkins Applied Physics Lab where thousands of people came out to celebrate that encounter.

[Slide.]

But next view graph, I think even more importantly there's the cover of the New York Times and below it little postage stamp images. I'm told that almost 450 newspapers put New Horizons and the exploration of Pluto on the front page the day after the flyby, that there were over 12 billion web hits, and I know that there were five television specials, one-hour-long specials made about this mission. People love exploration. That's the takeaway that we get. They really love it when we go new places and make new discoveries and do bold things, and I think the viral response of the media and the public to New Horizons is a testament to that and what we can do in NASA in the future.

Let me close with the next view graph.

[Slide.]

I was asked to say a word or two about a possible extended mission for New Horizons. The spacecraft is healthy and full of fuel and fully capable of flying a mission to explore further in the Kuiper belt. We have two potential targets, and working with NASA, we expect to choose between them later this summer. The National Academy of Sciences highly recommended this portion of the mission after Pluto through the Decadal Survey process and we're going to propose it for funding to NASA next year when NASA makes that call for proposals.

I'll take my last chart and I want to show you an image.

[Slide.]

It's of special significance not because of the scientific discovery of hazes in Pluto's atmosphere that this reveals. I'm sure many of you remember the iconic Apollo image of Earth rise over the moon, which was so iconic because it proved that the astronauts were there. It was a view that you could only get from being in orbit around the moon. Well, this image is taken from the far side of Pluto looking back to the planets silhouetted by the sun. It is proof that we went there, that we are now on the far side of Pluto, and that our nation can do great things.

Thank you.

[The prepared statement of Dr. Stern follows:]

Testimony before the House of Representatives
Committee on Science, Space, and Technology

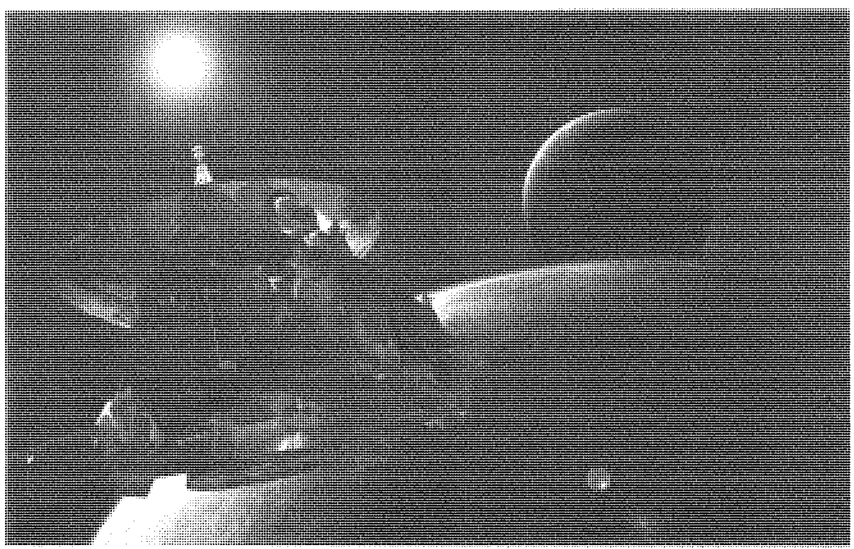
Exploration of the Solar System: From Mercury to Pluto and Beyond

Dr. Alan Stern
Principal Investigator
New Horizons Mission

National Aeronautics and Space Administration

PRESS KIT | July 2015

New Horizons Pluto Flyby



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NASA's New Horizons Nears Historic Pluto Flyby

In July 2015, NASA — and the United States — will complete the reconnaissance of the planets by exploring the Pluto system with New Horizons.

The fastest spacecraft ever launched, New Horizons has traveled more time and distance — more than nine years and three billion miles — than any space mission in history to reach its primary target. Its flyby of Pluto and Pluto's system of at least five moons on July 14 will complete the initial exploration of the classical solar system while opening the door to an entirely new realm of mysterious small planets and planetary building blocks in the Kuiper Belt.

The flyby will also cap a five-decade-long era of solar system reconnaissance that began with Venus and Mars in the early 1960s, and continued through first looks of Mercury, Jupiter and Saturn in the 1970s and Uranus and Neptune in the 1980s. Meaningfully, the July 14 flyby of Pluto will occur 50 years to the day after humans first explored Mars with NASA's Mariner 4 on July 14, 1965.

Reaching this "third" zona of our solar system — beyond the inner, rocky planets and outer gas giants — has been a space science priority for years, because it holds building blocks of our solar system that have been stored in a deep freeze for billions of years. In the early 2000s the National Academy of Sciences ranked the exploration of the Kuiper Belt — and particularly Pluto and its largest moon, Charon — as its top priority planetary mission for the coming decade. New Horizons — a compact, lightwaight, powerfully equipped probe packing the most advanced suite of cameras and spectrometers ever sent on a first reconnaissance mission — is NASA's answer to that call.

Pluto, the largest known body in the Kuiper Belt, offers an extensive nitrogen atmosphere, complex seasons, strangely distinct surface markings, an ice-rock interior that may harbor an ocean, and at least five moons for study. Among Pluto's five moons, its largest — Charon — may itself sport an atmosphere or an interior ocean, or both, and possibly even evidence of recent surface activity. The smaller moons (named Nix, Hydra, Styx and Kerberos) are scientifically valuable bonuses, since New Horizons officially began in 2001 as a mission to just Pluto and Charon, years before the four smaller moons were even discovered.

Hazards to flight could exist in the Pluto system due to debris ejected from Pluto's small satellites. New Horizons mission planners conducted an intensive search for hazards in May and June 2015 and were prepared, in the unlikely event that significant hazards were found, to divert the craft's trajectory or use its dish antenna as a shield to protect the spacecraft. On July 1, the team announced that the spacecraft would remain on its optimal path through the Pluto system instead of making a late course correction to detour around any hazards.

New Horizons' six-month encounter with the Pluto system started in January 2015 and culminates in the July flyby. Its suite of seven science instruments — which includes cameras, spectrometers, radio science, and plasma and dust detectors — will map the geology of Pluto and Charon; map their surface compositions and temperatures; examine Pluto's atmosphere and search for an atmosphere around Charon; study Pluto's smaller satellites; and look for rings and new satellites around Pluto.

Teams operating and navigating the spacecraft have been using ever-improving imagery from New Horizons to refine their knowledge of Pluto's location and skillfully guide New Horizons toward a target point about 7,750 miles (12,500 kilometers) from Pluto's surface. That targeting is critical, since the computer commands that will orient the spacecraft and point its science instruments are based on knowing the exact time and place that New Horizons passes Pluto.

And the work doesn't end with this July's flyby. Because it gets one shot at its target, New Horizons is designed to gather as much data as it can, as quickly as it can – taking about 100 times more data on close approach than it can send home before flying away. Although the spacecraft will send select, high-priority datasets home in the days just before and after close approach, the mission will continue returning the data stored in onboard memory for a full 16 months.

The New Horizons mission is one of the great explorations of our time; there's so much we don't know, not just about Pluto, but about similar worlds as well. Scientists won't be rewriting textbooks with this historic mission — they'll be writing them from scratch.

The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, manages the New Horizons mission for NASA's Science Mission Directorate in Washington, DC. Alan Stern, of the Southwest Research Institute, is the principal investigator and leads the mission. SwRI leads the mission, the science team, payload operations and encounter science planning. APL designed, built and operates the New Horizons spacecraft. New Horizons is part of the New Frontiers Program, managed by NASA's Marshall Space Flight Center in Huntsville, Alabama.

For more information on New Horizons, visit: http://www.nasa.gov/newhorizons and http://pluto.jhuapl.edu.

Media Services Information

News and Status Reports

NASA and the New Horizons team will issue periodic status reports on mission activities and make them available online at www.nasa.gov/newhorizons and http://pluto.jhuapl.edu. NASA will release several "Notes to Editors" before the Pluto flyby with details of press accreditation, media briefings, special press opportunities, on-site logistics at the Johns Hopkins Applied Physics Laboratory, and NASA TV and Web coverage.

NASA Television

NASA Television is carried on the Web and on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. It is available in Alaska and Hawaii on AMC-7, at 137 degrees west longitude, transponder 18C, at 4060 MHz, horizontal polarization. A Digital Video Broadcast compliant Integrated Receiver Decoder is required for reception. For NASA TV information and schedules on the Web, visit www.nasa.gov/ntv.

On-Site Media Logistics

News media representatives covering the Pluto flyby in person must be accredited through NASA and the Johns Hopkins Applied Physics Laboratory. Registration ended June 30, 2015. Journalists may call (240) 228-7536 for more information. Resources for journalists, including media guidelines, and a map of APL's main campus may be found at http://www.jhuapl.edu/MediaResources/.

New Horizons on the Web

New Horizons information — including an electronic copy of this press kit, press releases, fact sheets, mission details and background, status reports and images — is available on the Web at http://pluto.jhuapl.edu and www.nasa.gov/newhorizons. Mission updates are also available on Twitter (@NASANewHorizons) and Facebook (www.facebook.com/new.horizons1).

Quick Facts

Mission

Launch: January 19, 2006, from Launch Complex 41 at Cape Canaveral Air Force Station, Florida.

Launch vehicle: Lockheed Martin Atlas V-551 (core Atlas booster [with five solid rocket boosters attached] with a Centaur upper stage); and a Boeing STAR-48B solid-propellant rocket third stage.

Launch vehicle height (with payload): 59.7 meters (196 feet).

Launch vehicle weight (fully fueled): Approximately 575,000 kilograms (1.26 million pounds).

Jupiter Gravity Assist: February 28, 2007.

Jupiter closest approach distance and speed at Jupiter: About 2.3 million kilometers (1.4 million miles) at 21 kilometers per second (47,000 miles per hour).

Planetary Orbit Crossings: Moon (9 hours after launch); Mars (April 7, 2006); Asteroid APL (June 13, 2006); Jupiter (Feb. 28, 2007); Saturn (June 8, 2008); Uranus (March 18, 2011); Neptune (Aug. 25, 2014).

Pluto system flyby: July 14, 2015

Pluto closest approach distance and speed: 12,500 kilometers (about 7,750 miles) at approximately 14 kilometers per second (31,000 miles per hour.)

Planned Charon closest approach and speed: About 29,000 kilometers (18,000 miles) at same approximate Pluto flyby speed.

One-way speed-of-light (radio transmission) time from Pluto to Earth in July 2015: 4 hours, 25 minutes.

Pluto distance from Earth in July 2015: Approximately 4.77 billion kilometers (2.97 billion miles, or just under 32 astronomical units).

Spacecraft

Size: The primary structure is about the size of a baby grand piano; 0.7 meters (27 inches) tall, 2.1 meters (83 inches) long and 2.7 meters (108 inches) at its widest. A 2.1-meter (83-inch) diameter antenna dish is attached to the top deck; the spacecraft measures 2.2 meters (87 inches) tall from the payload attachment fitting on the bottom deck to the top of the dish antenna stack.

Launch weight: 478 kilograms (1,054 pounds); included 77 kilograms (170 pounds) of hydrazine propellant and a 30-kilogram (66-pound) science instrument payload.

Power: Total power available for the Pluto encounter is 202 watts from a single radioisotope thermoelectric generator.

Propulsion: 16 hydrazine-fueled thrusters, used for trajectory adjustments and attitude control.

Science instruments: The New Horizons science payload is the most capable

A Mission of Many Firsts

New Horizons is the first . . .

- mission to Pluto
- mission to a double planet
- mission to an ice dwarf planet
- mission to study Kuiper Belt Objects
- mission since Voyager in the 1970s to an unexplored planet
- principal investigator (PI)-led outer planets mission
- planetary mission to carry a student-built instrument
- outer planets mission led by the Johns Hopkins Applied Physics Laboratory and Southwest Research Institute
- NASA New Frontiers mission

New Horizons is also the fastest spacecraft ever launched, has traveled the farthest distance to reach its primary science target, and completes the first reconnaissance of our solar system's family of planets.

suite of instruments ever launched on a first reconnaissance mission to an unexplored planet. It includes an ultraviolet imaging spectrometer to probe atmospheric composition and surface structure; a visible and infrared camera/spectrometer to obtain high-resolution color maps and surface composition maps; a long-range telescopic camera for high-resolution surface images; particle spectrometers to measure solar wind charged particles in and around Pluto's atmosphere; a detector to measure masses of space-dust particles; and two copies of a radio science experiment to examine atmospheric structure, surface thermal properties and the planet's mass.

Program

First mission in NASA's New Frontiers Program, a class of principal investigator-led projects larger than Discovery missions.

Cost: Approximately $720 million (including spacecraft and instrument development, launch vehicle, mission operations, data analysis, and education/public outreach) covering 2001 — 2017.

Meet Pluto

General

- First dwarf planet discovered by an American, Lowell Observatory astronomer Clyde Tombaugh in 1930.
- It is the final classical planet in the solar system to be visited by a spacecraft.
- Pluto has five known moons — Charon, discovered in 1978; Nix and Hydra, discovered in 2005; Styx, discovered in 2011; and Kerberos, discovered in 2012.
- Charon is so large (half of Pluto's size, same diameter as Texas) that the Pluto-Charon system makes up a "double planet," the only one in our solar system. Together Pluto and Charon orbit around their common center of gravity in the space between them.
- Pluto is unusually difficult to study from Earth because it is so small and far away. It is 50,000 times fainter than Mars, with less than 1% of the red planet's apparent diameter when viewed from Earth.
- Pluto is the largest and brightest known member of the Kuiper Belt — the solar system's third zone — the vast region of ancient, icy, rocky bodies stretching almost 2 billion miles beyond Neptune's orbit.
- The International Astronomical Union controversially opted in 2006 to classify Pluto and recently discovered large Kuiper Belt Objects as dwarf planets; debate continues on Pluto's planetary classification.

Orbit

- Orbits the Sun once every 248 Earth years.
- Average distance from the Sun is 5.9 billion kilometers (3.7 billion miles), about 40 times farther out than Earth.
- Elliptical (oval-shaped) orbit; ranging from 4.4 billion kilometers (2.8 billion miles) to 7.4 billion kilometers (4.6 billion miles) from the Sun.
- Latest closest approach to the Sun was in 1989; from 1979-1999 Pluto was closer to the Sun than Neptune.
- Orbit is tilted 17 degrees from the ecliptic plane — the plane where the inner planets orbit the Sun — a higher "inclination" than terrestrial planets or gas giants (Mercury is next at 7 degrees).
- Pluto is tipped on its side — its rotational north pole is tilted 118 degrees from celestial north, or 28 degrees below the ecliptic plane.
- Pluto and Charon both rotate every 6.4 Earth days.
- Charon orbits Pluto once every 6.4 Earth days, from a distance of 19,636 kilometers (12,201 miles); Charon orbits at Pluto's "synchronous" distance, with one side always facing Pluto.
- Pluto and Charon are locked in a gravitational resonance where not only does Charon keep the same face to Pluto (just like Earth's moon faces Earth) but also, Pluto always sees the same face of Charon.

Physical Characteristics: Pluto

- Exact diameter is uncertain to about +/-25 kilometers, but close to 2,380 kilometers (1,500 miles); the circumference around Pluto's equator is the same as the distance from Manhattan to Maui.
- Surface composition includes nitrogen, carbon monoxide, methane and ethane ices; many other materials may also be present, but undiscovered.
- Has a tenuous but complex atmosphere made mostly of nitrogen, with traces of methane, carbon monoxide, and some heavier hydrocarbons.
- The atmosphere undergoes extreme seasonal changes as Pluto orbits the Sun.
- Atmospheric surface pressure is currently about 50,000 times less than on Earth, about 300 times less than on Mars.
- Low surface gravity, about 6% of Earth's.
- Estimated surface temperature is about minus-233 degrees Celsius (minus-387 degrees Fahrenheit).
- Has a density about twice that of water, indicating it is composed of a mixture of 35% ice and 65% rocky material.
- With ranges of very bright and dark areas, Pluto's surface has more contrast than any planet in the outer solar system.

Physical Characteristics: Charon

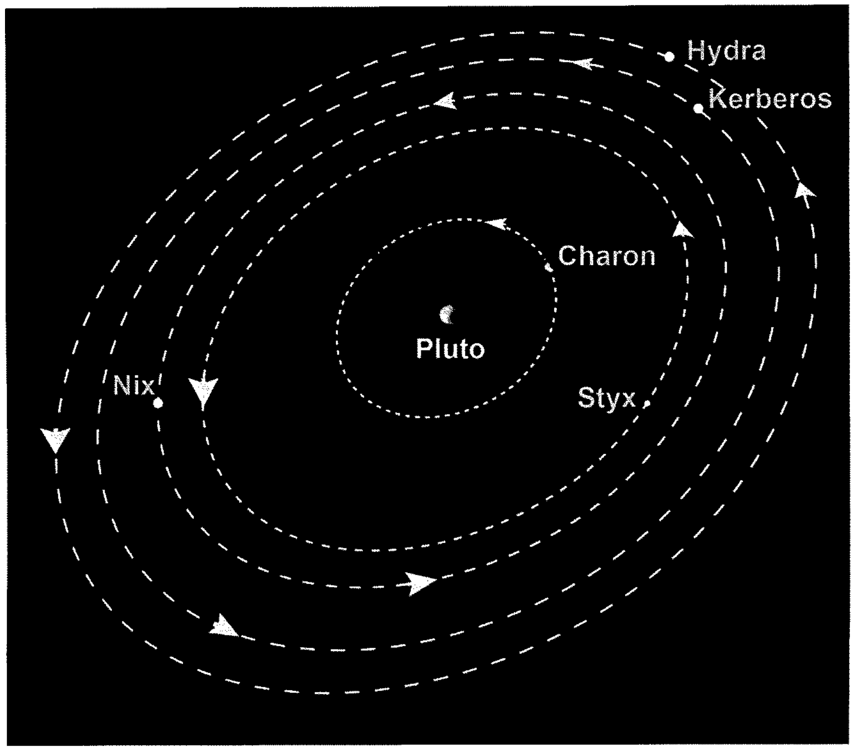
- Diameter is about 1,200 kilometers (745 miles), the largest satellite relative to the planet it orbits.
- Surface known to be mostly water ice, possibly also including ammoniated hydrates.
- No detectable atmosphere (from Earth-based studies).
- Like Pluto, its density (about twice that of water) indicates it is composed of a mixture of 50% ice and 50% rocky material.

Fast Facts: Hydra, Nix, Styx, Kerberos

Pluto's smaller moons have been hard to study in any detail from afar. New Horizons will change that by flying past them in July 2015, but we do know a few things:

- Hydra is the outermost known moon, orbiting Pluto every 38 days at a distance of approximately 64,700 kilometers (40,200 miles).
- Nix orbits every 25 days at a distance of 48,700 kilometers (30,300 miles).
- Estimated diameters of Nix and Hydra are between 40-150 kilometers (25-95 miles).
- Styx circles Pluto every 20 days between the orbits of Charon and Nix, and is likely just approximately 7 to 21 kilometers (4 to 13 miles) in diameter.
- Kerberos orbits between Nix and Hydra with a 32-day period; estimated diameter is approximately 10 to 30 kilometers (6 to 20 miles).
- Styx and Kerberos are 20 to 30 times fainter than Nix and Hydra.

For more on what we know about the Pluto system — that is, before New Horizons revolutionizes that knowledge — visit: http://pluto.jhuapl.edu/Pluto/index.php



The Pluto system, with (not to scale) orbits of Pluto's five known moons.

Why Pluto and the Kuiper Belt?

The Science of New Horizons

Since the day it was discovered 85 years ago, Pluto has been a harbinger of the mysteries on the far planetary frontier. With its discovery in 1930, Pluto became a preview of the icy, rocky objects in what would become known as the Kuiper Belt. And as history has already told us, it was just the first glimpse of other incredible scientific finds.

In the early 2000s, owing to the great scientific interest in Pluto as well as in the ancient, icy Kuiper Belt of miniature planets, smaller worlds and comets, the U.S. National Academy of Sciences ranked a Pluto-Kuiper Belt mission its highest priority for a New Frontiers mission start in that decade. New Horizons is that mission.

The Third Zone

The discovery of the Kuiper Belt in the last quarter-century sparked a fundamental change — a revolution, really — in how we view the solar system. This new "third zone" swirling beyond both the inner zone of rocky planets (Mercury, Venus, Earth and Mars) and the middle zone of the gas giants (Jupiter, Saturn, Uranus and Neptune), turns out to be largest structure in our planetary system — holding an estimated 100,000-plus miniature worlds with diameters larger than 100 kilometers — and it is the source of short-period comets. It is also home to a handful of small planets, of which Pluto is the largest, brightest and first discovered.

A New Kind of Dwarf Planet

For decades after young American astronomer Clyde Tombaugh discovered Pluto in 1930, this small world was considered an oddball. The other planets fit neatly into the known architecture of the solar system — four small, rocky bodies in the inner orbits and four gas giants in the outer orbits, with an asteroid belt in between. Distant Pluto was an icy stranger in a weird orbit.

By the 1950s, some researchers, most notably Dutch-American astronomer Gerard Kuiper, had suggested that Pluto was not a lone oddity but the brightest of a vast collection of objects orbiting beyond Neptune. This concept, which became known as the Kuiper Belt, appeared in scientific literature for decades, but repeated searches for this population of frosty comets came up short.

In the late 1980s, scientists determined that only something like the Kuiper Belt could explain why short-period comets orbit so close to the plane of the solar system. This circumstantial evidence for a distant belt of bodies in the same region as Pluto drove observers back to their telescopes in search of undiscovered, faint objects. This time, though, they had technology on their side: telescopes with CCD cameras made searches far more sensitive than work done previously with photographic plates.

In 1992, astronomers at the Mauna Kea Observatory in Hawaii discovered the first Kuiper Belt Object (KBO), which was about 20 times smaller and almost 10,000 times fainter than Pluto. Since then, observers have found more than 1,000 KBOs, with diameters ranging from 50 to almost 2,400 kilometers (30 to 1,240 miles) — and researchers estimate that the Kuiper Belt contains more than 100,000 objects larger than 100 kilometers (about 60 miles) across. In essence, the Kuiper Belt has turned out to be the big brother of the asteroid belt, with more mass, more objects, and a greater supply of ancient, icy and organic material left over from the birth of the planets than imagined.

The Kuiper Belt's discovery made it clear that Pluto is not an anomalous body, but one of a new class of bodies orbiting 5 billion kilometers (3 billion miles) — and beyond — from the Sun. Because this far-off region may hold important clues to the early development of the solar system, planetary scientists are very interested in learning more about Pluto and its moons and their Kuiper Belt cousins.

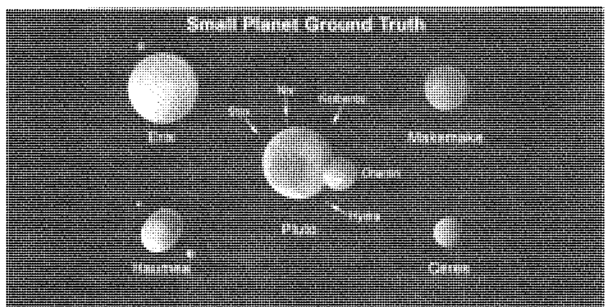
The region is too far to observe from Earth in any detail; even the Hubble Space Telescope shows only blurry patches of light and dark materials on Pluto's surface. And although the Pioneer, Voyager and Galileo spacecraft provided scientists with marvelous up-close images and other data to reveal Jupiter, Saturn, Uranus and Neptune, no space probe has ever visited Pluto or observed objects in the Kuiper Belt — until now.

Astronomical Archeology

Exploring the Kuiper Belt is an archeological dig into the earliest days of the solar system — a close-up look at the remnants of the ancient planet-building process that hold critical clues to the history of the outer solar system, objects whose pristine chemistry has been held in 'deep freeze' that acts like a time capsule. Scientists are using New Horizons to explore the region, so getting a valuable first glimpse of the long-gone era of planetary formation.

Why are astronomers so interested in studying Pluto and the Kuiper Belt? For one, the size, shape and general nature of the Kuiper Belt appear to be much like belts seen around other nearby stars. Additionally, when researchers used computer-modeling techniques to simulate the formation of KBOs as the solar system was coalescing from a whirling disk of gas and dust, they found that the ancient Kuiper Belt may have been at least 10 times more massive than it is today to give rise to Pluto-Charon and the KBOs we see. In fact, there may once have been enough solid material to have formed another planet the size of Uranus or Neptune in the Kuiper Belt. And the same simulations revealed that large planets would have naturally grown from the KBOs in a very short time had nothing disturbed the region.

But something disrupted the Kuiper Belt at about the time Pluto formed. Was it Neptune's formation near the belt's inner boundary? Perhaps instead it was the gravitational influence of a large number of planetary embryos — rocky bodies thousands of kilometers across — moving rapidly through the Kuiper Belt after they were ejected by Uranus and Neptune from their own formation zones. Or maybe it was something else altogether. Whatever the cause, the Kuiper Belt apparently lost most of its mass, and the growth of bodies in the region suddenly stopped.



New Horizons is humankind's first opportunity to explore an entirely new class of worlds — the small planets. Pluto is largest and best known, but there are others — including Ceres, the target of NASA's Dawn mission in 2015.

Why Study the Pluto System?

Pluto is a new type of planet. Neither a terrestrial planet nor a gas giant, it is an ice dwarf, common to the deep outer solar system. Studying Pluto will shed light on the other small planets of the Kuiper Belt.

Pluto-Charon is the solar system's only known binary planet, with implications for atmospheric transfer and for better understanding of how the Earth-Moon system formed.

Pluto's atmosphere provides the only chance to observe planetary hydrodynamic escape, the process believed to have shaped Earth's primordial atmospheric loss.

Pluto's and Charon's surfaces tell the history of outer solar system bombardment. Comparing Pluto's cratering record with Charon's should yield a direct comparison of present-day and historical impacts. Because of continual sublimation and condensation of frost, Pluto's surface is considered "young" while Charon's, because of the apparent lack of atmosphere, is "old."

Pluto System Science Highlights

1930: Pluto discovered

1954: Pluto's 6.4 day rotation period discovered

1965: Pluto's 3:2 orbit resonance with Neptune discovered

1976: Discovery of methane ice on Pluto

1978: Charon discovered; mass of Pluto-Charon determined

1980: Stellar occultation — observing a star as a planet passes in front of it — reveals Charon's diameter to be near 1,200 kilometers (about 750 miles)

1985: First direct detection of Charon by transits across Pluto's disk; telescopic evidence of polar caps

1986: First reliable radii for Pluto and Charon determined

1987: Water-ice discovered on Charon's surface

1988: Discovery that Pluto's orbit is chaotic; stellar occultation reveals Pluto's atmosphere

1992: Nitrogen and carbon monoxide ices found on Pluto

2005: Nix and Hydra discovered

2006: NASA's New Horizons spacecraft launched, ammonium hydrates discovered on Charon

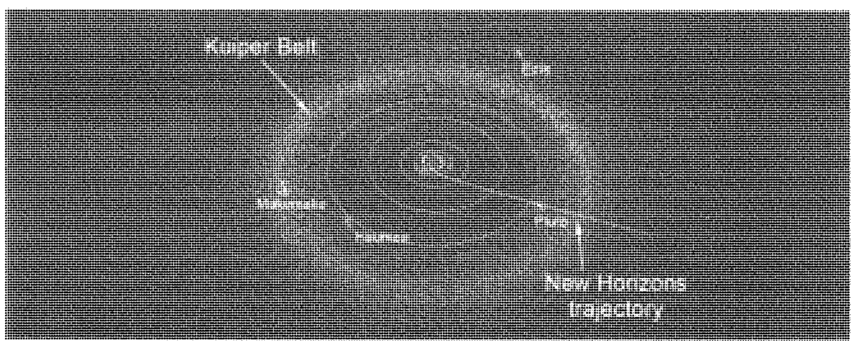
2011: Kerberos discovered

2012: Styx discovered

2015: New Horizons arrives at Pluto

Uncovering the Kuiper Belt

The first Kuiper Belt Object was discovered in 1992: a 100-kilometer (60-mile) sized object in a near-circular orbit well beyond Pluto. Astronomers found four more in 1993 and 10 more the following year. Today there are more than 1,000 detected objects in the Kuiper Belt. Most are very small compared to Pluto.



Larger Kuiper Belt Objects shown in relation to Pluto's location and New Horizons' path through the solar system.

A Scientific Priority

What little we do know about the Pluto system tells us it's a scientific wonderland. Pluto's large, Texas-sized moon Charon has a diameter of about 1,200 kilometers (750 miles), more than half that of Pluto's size, making it the largest moon in the solar system compared to the planet it orbits. (In contrast, most satellites are only a few percent of their parent object's diameter.) Because the two bodies are so close in size, and because they orbit about a center of mass that is outside Pluto's surface (known as a barycenter), Pluto-Charon is considered a double planet. No other planet in our solar system falls into this category — although the Earth-moon system comes close — but astronomers have discovered many double asteroids and double KBOs. There is now little doubt that binary objects like Pluto-Charon are common in our solar system, and most likely in others. New Horizons is the first trip to a binary world.

Astronomers are eager to know how a system like Pluto and its moons could form. The prevailing theory: Pluto collided with another large body in the distant past, and much of the debris from this impact went into orbit around Pluto and eventually coalesced to form Charon. Because scientists believe that a similar collision led to the creation of Earth's moon, the study of Pluto and Charon could help scientists decipher the history of our own planet.

Researchers also want to understand why Pluto and Charon look so different. From Earth, the Hubble Space Telescope and New Horizons, we have seen that Pluto has a reflective surface with distinct markings that indicate polar caps. Charon's surface is far less reflective, with indistinct markings. And where Pluto has an atmosphere, Charon apparently does not. Is the sharp dichotomy between these two neighboring worlds a result of divergent evolution, perhaps owing to their different sizes and compositions. Or is it a consequence of how they originally formed? New Horizons will begin to answer these questions.

Pluto's density, size and surface composition are strikingly similar to those of Neptune's largest satellite, Triton — itself a captured planet from the Kuiper Belt. A great surprise of Voyager 2's exploration of the Neptune system was the discovery of ongoing cryovolcanic activity on Triton. Will Pluto or other KBOs display such activity? New Horizons will provide insight that guides us to a better understanding of these small worlds.

Yet another allure of Pluto is its fascinating and surprisingly complex atmosphere. Although Pluto's atmosphere is about 300-600 times less dense than Mars' — which is, in turn, about 150 times less dense than Earth's — it offers unique insights into the workings of related planetary atmospheres at Triton and Titan. Whereas the Earth's atmosphere contains only one gas (water vapor), and Mars contains two (water vapor and carbon dioxide), that regularly transitions between solid and gas, Pluto's atmosphere contains three: nitrogen, carbon monoxide and methane.

2015: The Year of the Dwarf Planet

NASA's Dawn spacecraft arrived at dwarf planet Ceres in April 2015. Data from Dawn and New Horizons gathered this year will teach us much about the least-explored class of planet in our solar system.

Furthermore, Pluto's surface temperature varies greatly because of the planet's eccentric orbit and polar tilt. Pluto reached its closest approach to the Sun in 1989. As the planet moves farther away and cools, most astronomers think the average surface temperature will eventually drop and most of the atmosphere will freeze out on the surface. As a result of this, and because the planet is essentially tipped on its side, with its rotational north pole 28 degrees below the ecliptic plane, Pluto may have the most complex seasonal patterns in the solar system.

What's more, scientists believe Pluto's atmosphere bleeds into space — a lot. The thermal energy of typical molecules in the upper atmosphere is sufficient to escape Pluto's gravity, a process called hydrodynamic escape. Although we do not see hydrodynamic escape on any other planet today, it may have been responsible for the rapid loss of hydrogen from Earth's atmosphere early in our planet's history. In this way, hydrodynamic escape may have helped make Earth suitable for life. Pluto is the only place in the solar system where we can study this process on a planetary scale today.

Another important connection between Pluto and life on Earth is the likely presence of organic compounds (such as frozen methane) on Pluto's surface and water ice inside the dwarf planet. Recent observations of smaller KBOs show that they, too, most likely harbor large amounts of ice and organics. Such objects are thought to have routinely strayed into the inner part of the solar system billions of years ago, collided with Earth, and helped to seed the young Earth with the raw materials of life.

Given all these fascinating scientific motivations, it is easy to understand why the planetary research community wanted to send a spacecraft to Pluto and the Kuiper Belt.

Core Science

New Horizons' core science goals reflect what the science community has wanted to learn about Pluto for nearly three decades. The craft will map the surfaces of Pluto and Charon with an average pixel scale of one kilometer (Hubble Space Telescope's best Pluto and Charon is about 500 kilometers). It will map the surface composition across the various geological provinces of the two bodies. And it will determine the composition, structure and escape rate of Pluto's atmosphere. NASA has also outlined a list of lower priorities, including the measurement of surface temperatures, topographic mapping, and the search for additional satellites or rings around Pluto.

New Horizons began its study of the Pluto system in January 2015, six months before closest approach. In late April 2015, when the craft was less than 100 million kilometers (65 million miles) from Pluto, its images of the planet began to exceed what we could take with the best telescopes on or around Earth.

In the weeks leading up to closest approach, the mission team will begin to map Pluto and Charon in increasing detail and observe phenomena such as Pluto's weather by comparing images of the planet over time. It will take high-resolution views of Pluto and its moons to decide which geological features receive top-priority focus. The highest-resolution images will be 70 meters per pixel.

During close approach — the closest point coming 12,500 kilometers (about 7,750 miles) from Pluto's surface — New Horizons' imagers will map the entire surface structure of the sunlit faces of Pluto and Charon and also map the surface compositions.

Once the spacecraft passes Pluto, it will turn around and try to map the planet's night side, which will be softly illuminated by the moonlight from Charon. Also at this time, the spacecraft's antenna will receive a powerful radio beam from Earth, aimed so that it passes through Pluto's atmosphere. By measuring the effects of atmospheric refraction on the radio beam as it travels to the spacecraft, and similar effects on ultraviolet sunlight passing through the atmosphere, scientists will be able to map the temperature, density and composition profile of the atmosphere all the way to the surface.

Science Objectives

Based largely on what the scientific community wanted to learn about Pluto and Charon, NASA prioritized its science goals for Pluto system exploration in three categories:

Required

- Characterize the global geology and morphology of Pluto and its moons
- Map surface composition of Pluto and Charon
- Characterize the neutral atmosphere of Pluto and its escape rate

Important

- Characterize the time variability of Pluto's surface and atmosphere
- Image Pluto and Charon in stereo
- Map the terminators (day/night boundary) and compositions of selected areas of Pluto and Charon in high resolution
- Characterize Pluto's ionosphere and solar wind interaction
- Search for atmospheric hydrocarbons and nitriles
- Search for an atmosphere around Charon
- Determine albedos and surface temperatures on Pluto and Charon

Desired

- Characterize the energetic particle environment of Pluto and Charon
- Refine bulk parameters (radii, masses, densities) and orbits of Pluto and Charon
- Search for additional satellites, rings and magnetic fields

NASA defines mission success as meeting the "required" objectives. With its full science payload — three optical instruments, two plasma instruments, two radio science receivers/radiometers and a dust sensor — New Horizons plans to exceed these requirements, meeting or exceeding all of the objectives in each category.

New Horizons will also sample the density and composition of material escaping from Pluto's atmosphere, map surface temperatures across Pluto and Charon, search for Pluto's ionosphere, refine the diameters and masses of Pluto and its moons, search for dust particles in the Pluto system, and search for rings and additional moons — among other studies.

The first exploration of the Pluto system and, potentially, other objects in the Kuiper Belt is already inspiring and exciting the scientific community and the public. New Horizons will provide valuable insights into the origin of the outer solar system; the origin and evolution of planet—satellite systems likely formed by giant impacts; and the comparative geology, geochemistry, tidal evolution, atmospheres and volatile transport mechanics of icy worlds.

For more information on what we know about the Pluto system, visit the New Horizons websites at www.nasa.gov/newhorizons and http://pluto.jhuapl.edu.

New Horizons Science Team

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Composition (COMP) Theme Team Lead: Will Grundy (deputy: Dale Cruikshank)

Atmospheres (ATM) Theme Team Lead: Randy Gladstone (deputy: Mike Summers)

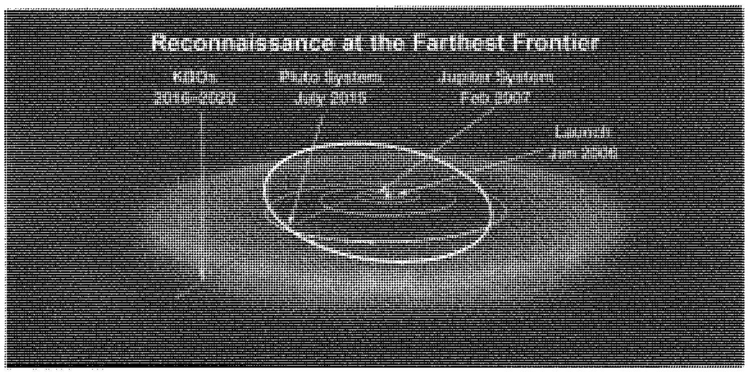
Particles and Plasma (P&P) Theme Team Lead: Fran Bagenal

Director of the Office of the Principal Investigator (DOPI): Cathy Olkin

Mission Overview

New Horizons will help us understand worlds at the edge of our solar system by making the first reconnaissance of Pluto and its system of moons — the last of the classical planets, and the first objects in the Kuiper Belt to be visited by spacecraft.

Packed with robust electronics and a full suite of the most powerful science instruments ever sent on a first reconnaissance planetary mission, the compact New Horizons probe is fortified for its long voyage of discovery. Launched on a powerful Atlas V rocket, New Horizons was the fastest spacecraft ever dispatched to the outer solar system, passing lunar orbit distance nine hours after launch and reaching Jupiter for a gravity assist and scientific studies just 13 months later. In January 2015, it began a six-month-long flyby study of the Pluto system. Then, should NASA approve, New Horizons will fly deeper into the Kuiper Belt to study a much smaller icy world — a planetesimal — in the vast region that begins a billion miles beyond Neptune's orbit.



The New Horizons path through the solar system.

Launch

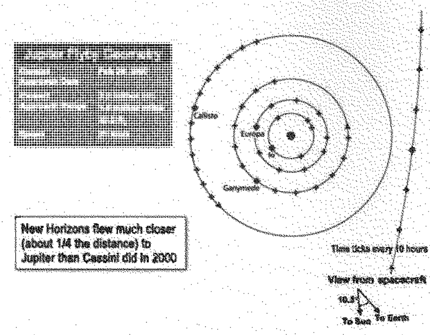
New Horizons lifted off from Launch Complex 41 at Cape Canaveral Air Force Station, Florida, on a Lockheed Martin Atlas V-551 launch vehicle on January 19, 2006. The Atlas V lifted off with 2,451,810 pounds (10,906,194 newtons) of force. (A newton is the unit of force needed to accelerate one kilogram of mass to one meter per second in one second.)

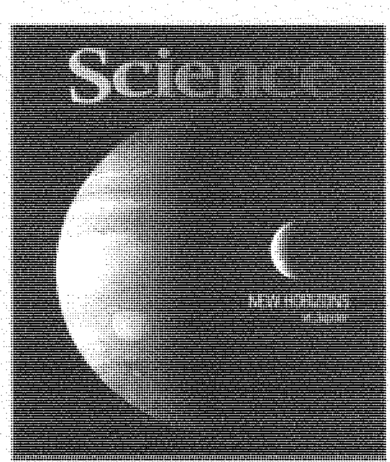
After it separated from its third stage, a STAR-48 solid-fuel booster, New Horizons sped from Earth at about 16 kilometers per second, or 36,000 miles per hour — the fastest spacecraft ever launched. New Horizons reached lunar orbit distance (about 384,000 kilometers or 238,600 miles from Earth) approximately nine hours after launch — the Apollo missions to the moon took about three days — and reached the Jupiter system in 13 months. During the 13 months en route to Jupiter, New Horizons conducted system and instrument checkouts, instrument calibrations, trajectory correction maneuvers, and rehearsals for the Jupiter science encounter.

Jupiter Gravity Assist

Launching in January 2006 allowed New Horizons to take advantage of a Jupiter gravity assist that shaved 3.7 years off the travel time to Pluto. Zooming past Jupiter on Feb. 28, 2007, New Horizons gained nearly 14,000 kilometers (9,000 miles) per hour from Jupiter's gravity, accelerating to a speed of over 83,600 km/h (52,000 mph) away from the Sun.

The Jupiter flyby also presented New Horizons with a unique opportunity to flight-test its instruments and pointing capabilities on an exciting set of scientific targets — Jupiter and its moons. New Horizons was the eighth spacecraft to visit Jupiter — but a combination of trajectory, timing and technology allowed it to explore details no probe had seen before, such as lightning near the planet's poles, the life cycle of fresh ammonia clouds, boulder-size clumps speeding through the planet's faint rings, the structure inside volcanic eruptions on its moon Io, and the path of charged particles traversing the previously unexplored length of the planet's long magnetic tail. New Horizons added to the legacy of Jupiter exploration begun with Pioneer and continued with Voyager, Galileo, Cassini and Juno, by publishing more than 100 scientific papers resulting from its flyby.





Read more about the Jupiter encounter at:
http://pluto.jhuapl.edu/Mission/The-Path-to-Pluto/Jupiter-Encounter.php

From January through June of that year, New Horizons' seven science instruments made more than 700 separate observations of the Jovian system, with most of them coming in the eight days around closest approach to Jupiter.

Hibernation

New Horizons "slept" for most of the cruise between Jupiter and Pluto in spin-stabilized hibernation mode. New Horizons spent 1,873 days in hibernation — about two-thirds of its flight time — spread over 18 separate hibernation periods from mid-2007 to late 2014 that ranged from 36 days to 202 days long. The last ended on Dec 6, 2014, when the team "woke" New Horizons to begin Pluto-encounter operations.

During hibernation, much of the New Horizons spacecraft was unpowered. The onboard flight computer monitored system health and broadcast a weekly beacon-status tone back to Earth. Onboard sequences sent in advance by mission controllers woke New Horizons two or three times each year to check out critical systems, calibrate instruments, gather science data, rehearse Pluto-encounter activities, and perform course corrections.

New Horizons pioneered routine cruise-flight hibernation for NASA. Not only did hibernation reduce wear and tear on the spacecraft's electronics, it also lowered operations costs and freed up NASA's Deep Space Network tracking and communication resources for other missions.

How Do You Get to Pluto? Practice, Practice, Practice

New Horizons team members view the Pluto flyby as the Super Bowl of space science — and you don't walk into the big game without practicing hard. In July 2013, the mission team converged on the Johns Hopkins Applied Physics Laboratory (APL) for a test of both team and spacecraft that replicated the closest nine days of flight toward and past Pluto — almost exactly as it will happen in July 2015.

Operators programmed New Horizons' onboard computers to "think" the spacecraft was approaching and passing Pluto, to the point it executed each command and movement of the actual encounter. Gathered at APL's campus in Laurel, Maryland, mission navigation and operations teams guided spacecraft activity in real time; the science team examined simulated data in the same way they'll download, analyze and distribute the real stuff when Pluto and its moons slowly reveal their secrets to New Horizons' seven science instruments.

The team and spacecraft accomplished everything they set out to do, and then some. Watch them gear up for this historic encounter on the planetary frontier in the two-part video found at: http://pluto.jhuapl.edu/News-Center/News-Article.php?page=20131223

Wake Up, New Horizons!

New Horizons joined the astronauts on four space shuttle missions who "woke up" to English tenor Russell Watson's inspirational "Where My Heart Will Take Me" — in fact, Watson himself recorded a special greeting and version of the song to honor New Horizons. The song was played in New Horizons mission operations upon confirmation of the spacecraft's final wake-up on Dec. 6 — listen to it at http://pluto.jhuapl.edu/News-Center/News-Article.php?page=20141206.

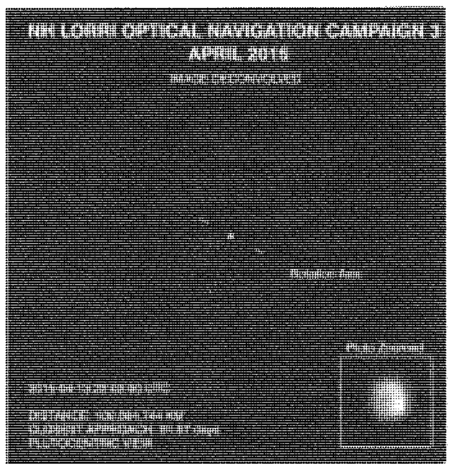
Approaching Pluto

After traveling some 5 billion kilometers (3 billion miles) and 9.5 years, New Horizons must thread a celestial needle by flying through a target circle only 300 kilometers (about 200 miles) in diameter — and with less than 100 seconds in timing error — to accomplish its science objectives. Fortunately, the team had a chance to guide New Horizons along the way.

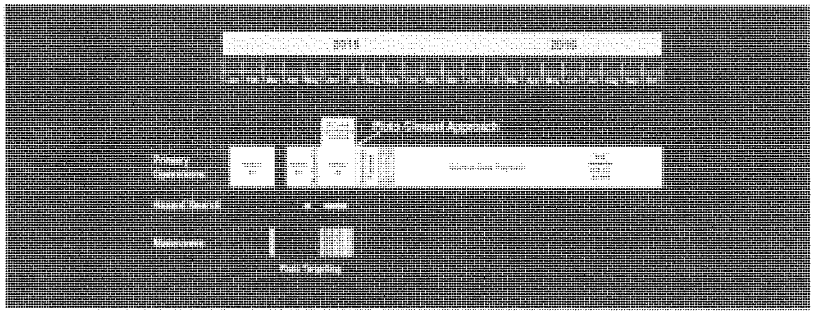
Since January 2015, the team has been taking detailed pictures of the Pluto system to help it refine the spacecraft's targeting and timing to reach the Pluto aim point. (This is called "optical navigation.")

The cameras and plasma and particle instruments on New Horizons actually started making measurements of the Pluto system in January 2015. Pluto and Charon first appeared as small, bright dots to New Horizons' cameras. But they and Pluto's smaller moons have appeared larger as the distance to encounter has decreased.

Pluto and Charon each rotate once every 6.4 Earth days. For the last four Pluto days before encounter (26 Earth days, or beginning around mid-June), the team will compile maps and gather spectra of Pluto and Charon every half-day. The team can then compare these maps to track changes over a Pluto day, at scales as small as about 30 miles (48 kilometers), which might indicate new snows or other weather.



Through the lenses of its telescopic Long Range Reconnaissance Imager, New Horizons "saw" surface features on Pluto — including what scientists think is a polar cap — for the first time in April 2015.



The Pluto encounter timeline. Find the latest encounter and observation plans online at http://pluto.jhuapl.edu.

Hazard Watch

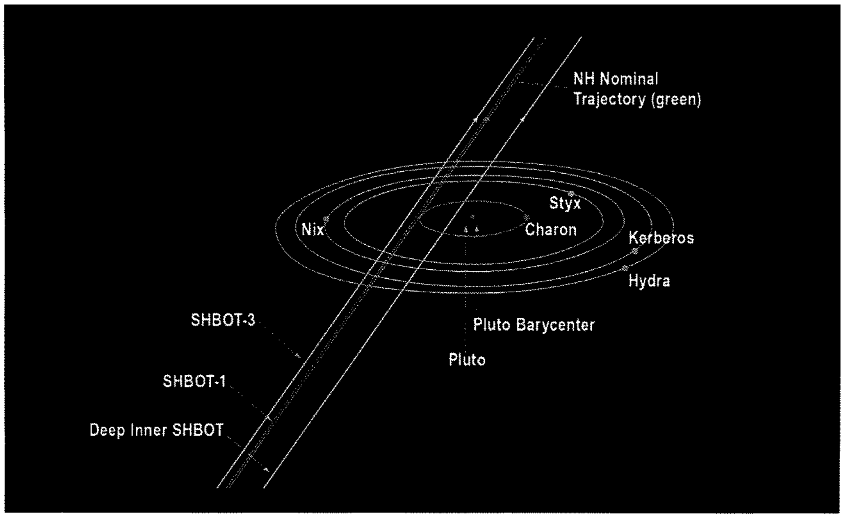
It seemed that whenever the New Horizons team used the Hubble Space Telescope to look harder at the Pluto system, it found additional moons: Nix and Hydra in 2005, Kerberos in 2011 and Styx in 2012.

The new moons made for attractive science targets, but they also raised serious concerns among the mission team. Objects smacking into Pluto and Charon might cause craters and debris, and on those larger bodies that debris likely falls back to the surface. Strikes on the smaller moons — because they have such low mass and gravity — could send debris into orbit around Pluto. And even tiny particles — no bigger than a grain of rice — can be lethal to a spacecraft blazing along at 30,000 miles per hour.

In 2011, the mission appointed a hazard-analysis team of scientists and engineers to examine this issue. They took spare parts left from the spacecraft build and re-tested them to check their hardness against impacts, and they designed models of expected dust behavior in the Pluto system. As the models gained more fidelity and more components were tested on Earth, those concerns began to ease. Estimates and models put the risk of a catastrophic strike at less than one percent.

Still, the team took precautions, which were especially important if New Horizons spotted new objects in the Pluto system. From mid-May to late June, the team embarked on an intense seven-week search for smaller satellites, larger dust and debris fields, and rings, using the telescopic LORRI (Long Range Reconnaissance Imager) instrument on the spacecraft. Should such hazards have blocked New Horizons' ideal path, the team could have shifted to one of three potential "Safe Haven by Other Trajectory" (SHBOT) plans to take the spacecraft out of harm's way. Operators could have also turned New Horizons so its dish antenna faced forward — in position to "ram" any debris in its path — to protect the instruments and spacecraft body underneath. Each SHBOT scenario cut the science return to varying degrees — some significantly — but those scenarios could have improved the chances of spacecraft survival and the successful downlink of science data. The team referred to the process to identify hazards and assess their danger — including decision-making to change the trajectory of New Horizons or the encounter sequence to protect against discovered hazards — as "seven weeks of suspense."

On July 1, the New Horizons team announced that the spacecraft would remain on its optimal path through the Pluto system instead of making a late course correction to detour around any hazards. Not finding new moons or rings present was a bit of a scientific surprise, but, as a result, no engine burn was needed to steer clear of potential hazards.



New Horizons Safe Haven by Other Trajectory (SHBOT) options.

Contingency Samples: The Apollo 11 astronauts quickly picked up "contingency samples" on their first visit to the moon, just in case something went wrong and Neil Armstrong had to quickly return to the lunar module. New Horizons has a similar plan to send home some of the best data stored on its recorders in the two days before it flies through the heart of the Pluto system, just in case hazards harm the spacecraft during close approach.

The Encounter

All told, New Horizons has approximately 30 specific scientific objectives planned for Pluto and its moons — from surface mapping and composition mapping to atmospheric studies and searches for new moons and rings. And in just the central nine days around closest approach — what the team has termed the "core encounter" — more than 380 observations are planned of Pluto, its moons, and the space between and around this system.

The busiest part of the Pluto system flyby will last one full Earth day, from about 12 hours before closest approach to about 12 hours after. On approach, the spacecraft will study ultraviolet emissions from Pluto's atmosphere and make its best global maps of Pluto and Charon in blue, red, infrared, and a special wavelength that is sensitive to methane frost on the surface. It will also take spectral maps in the near infrared, telling the science team about Pluto's and Charon's surface compositions at all locations, as well as the variation in temperature across the surface. New Horizons will sample material coming from Pluto's atmosphere, and will image all of Pluto's moons during this period.

At closest approach, the spacecraft comes 12,500 kilometers (about 7,750 miles) from Pluto and approximately 29,000 kilometers (about 18,000 miles) from Charon. During the half-hour when the spacecraft is closest to Pluto and Charon, it will take close-up pictures at both visible and near-infrared wavelengths. The best pictures of Pluto will depict surface features as small about 70 meters (about 230 feet) across — about the size of a football field. The spacecraft will also obtain stereo mapping products the team will use to reconstruct the topography of Pluto.

Even after the spacecraft passes Pluto, Charon and their four smaller companion moons, its work is far from done. Looking back at the mostly dark side of Pluto or Charon is the best way to spot haze in the atmosphere, to look for rings, and to

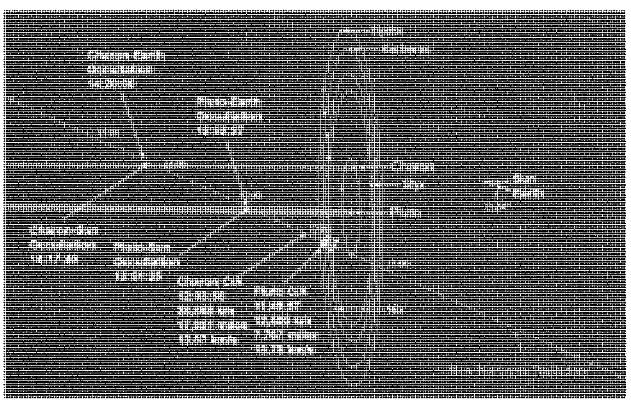
determine whether their surfaces are smooth or rough. Also, the spacecraft will fly through the shadows cast by Pluto and Charon and observe both the Earth and Sun setting, and then rising, through Pluto's atmosphere. It will watch the light from the Sun and pick up radio waves from transmitters on Earth, making measurements that will reveal the composition, structure, and thermal profile of Pluto's atmosphere in exquisite detail. The spacecraft will also obtain images of Pluto's night side, illuminated by Charon, which casts about as much light onto Pluto as a quarter moon on Earth.

Similar measurements were made by spacecraft like the Voyagers and the Mariners on first flybys of planets. However, New Horizons also brings some revolutionary new capabilities to bear — such as temperature and composition mapping capabilities and a dust detector to detect tiny debris particles near Pluto. These kinds of instruments were not available when the Mariner and Voyager spacecraft were flown.

New Horizons will approach Pluto from the planet's northern hemisphere, which will be sunlit; the southern pole will be dark. The spacecraft flies toward Pluto at a solar phase angle of 15 degrees — excellent lighting conditions for imaging.

In July 2015, Pluto will be just under 3 billion miles (about 5 billion kilometers) from Earth — about 32 times the distance between the Sun and Earth. The one-way light time delay — the time for a radio signal to reach New Horizons from Earth — at that distance is 4 hours and 25 minutes. Timing has to be precise: the team must transmit the signals used for probing the atmosphere with the Radio Science Experiment (REX) 4 hours and 25 minutes before the anticipated Earth occultation time.

The entire encounter sequence has been intricately choreographed and will be precisely programmed in New Horizons' redundant flight computers. In fact, mission operators will not have continuous contact with New Horizons during the flyby since the spacecraft will be continuously reorienting itself to collect data on Pluto and its moons. New Horizons was designed to collect as much data as possible, as quickly as possible, and then store that data on its solid-state digital recorders.



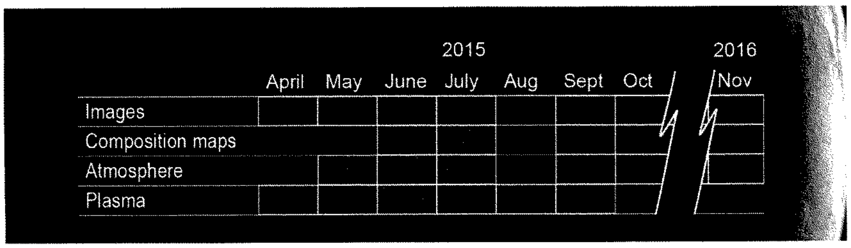
New Horizons trajectory through the Pluto system. Times are UTC; timeline "ticks" are 10 minutes. Distances are from the surfaces of Pluto and Charon; flyby speeds are relative to each body; position and lighting of each body is at the time of Pluto close approach.

Long Distance Data

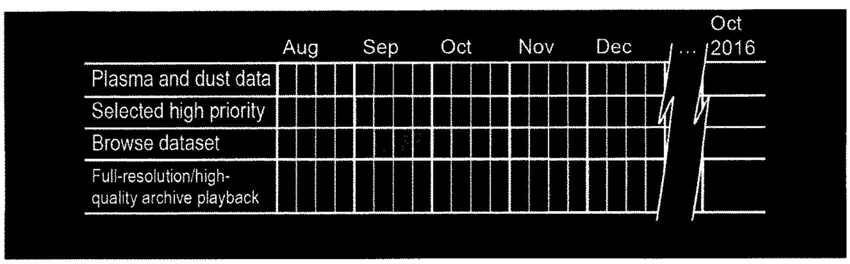
A major challenge for the New Horizons mission is the relatively slow "downlink" rate at which data can be transmitted to Earth, especially when you compare it to rates now common for high-speed Internet surfers.

During the Jupiter flyby in February 2007, New Horizons sent data home at about 38 kilobits per second (kbps). The average downlink rate after New Horizons passes Pluto (and sends the bulk of its encounter data back to Earth) is approximately 2 kilobits per second, a rate the spacecraft achieves by downlinking with both of its transmitters through NASA's largest antennas. Even then, it will take until late 2016 to bring down all the encounter data stored on the spacecraft's recorders.

Since New Horizons must share time on NASA's Deep Space Network with other missions, the team plans to produce a compressed, "browse" data set that can be sent to Earth more quickly. The browse data will be downlinked before the end of 2015, followed by the complete dataset by late 2016.



No weekend at Pluto: The New Horizons Pluto encounter is not a typical planetary flyby with a flurry of immediate data collection and transmission. Owing in part to the low transmission rates from Pluto, the spacecraft will be sending data back to Earth long (16 months) after it has finished collecting it; as a result, many of the mission's major discoveries will be made from examining data that arrives late in 2015 or during 2016, well after New Horizons flies through the Pluto system. In that respect, the science cadence will more closely resemble an orbiter mission, in the way Cassini had many initial findings on Saturn orbit insertion, followed by years of ongoing results.



Types of data scheduled for downlink through the entire Pluto encounter.

Into the Kuiper Belt — and Beyond

The decadal survey that called for the exploration of Pluto also insisted in the exploration of small KBOs that were the building blocks of planets like Pluto. So, after passing through the Pluto system, the spacecraft will be retargeted for an encounter with a small Kuiper Belt Object. New Horizons carries more than enough hydrazine fuel for such a KBO flyby; its communications system is designed to work from far beyond Pluto and its scientific instruments can work in light levels even lower than the dim sunlight at Pluto, where the sun is currently only 1/1000th as bright as it is at Earth.

The New Horizons team conducted a dedicated search for small KBOs the spacecraft could reach. In the early 2000s, no such KBOs had even been discovered. The National Academy of Sciences recommended that New Horizons fly by small KBOs about 20 to 50 kilometers (about 12 to 30 miles) across, which are more likely to be primitive bodies (less well-formed than planets like Pluto).

In 2014, using the Hubble Space Telescope, New Horizons science team members discovered three KBOs — all in the range of 20-55 kilometers across, and all with possible flyby dates in early 2019 — a record-setting billion miles beyond Pluto. In summer 2015, after the Pluto flyby, the New Horizons team will work with NASA to choose the best candidate among the three. This autumn, operators will fire the engines aboard New Horizons — at the optimal time to minimize the fuel required to reach the selected target — to begin the new journey to the selected KBO.

The team will then submit a formal proposal to explore additional KBOs in 2016; if NASA approves, the New Horizons Extended Mission would begin in 2017.

After that, the spacecraft will continue beyond the Kuiper Belt and into interstellar space, possibly on a second extended mission, if NASA approves. Like the Pioneer and Voyager spacecraft, New Horizons will escape the Sun's gravity and fly out into interstellar space — never to return to our solar system.

Mission Operations

New Horizons mission operations are conducted from the Mission Operations Center at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, where the spacecraft was designed and built. Flight controllers and mission analysts plan, and monitor and operate the spacecraft, working closely with the multi-institutional science team, the science operating team in Boulder, Colorado, the mission design team at APL, and the navigation team at KinetX, Inc., based in Simi Valley, California.

The instruments aboard New Horizons are operated by command sequences generated by staff at APL and the Southwest Research Institute (SwRI). The mission's Tombaugh Science Operations Center (SOC), located at SwRI in Boulder, processes all instrument data for the science team, and it will produce data archives for the scientific community and public at large.

Like all NASA interplanetary missions, New Horizons relies on the agency's Deep Space Network of antenna stations to track and communicate with the spacecraft. The stations are located in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. All three complexes communicate directly with the control center at NASA's Jet Propulsion Laboratory, Pasadena, California.

Data received on Earth through the Deep Space Network is sent to the New Horizons Mission Operations Center at APL, where data are "unpacked" and stored. The mission operations and instrument teams scour the engineering data for performance trend information, while science data is copied to the SOC in Boulder. At the Science Operations Center, data passes through "pipeline" software that converts the data from instrumental units to scientific units, based on calibration data obtained for each instrument. Both the raw and calibrated data files are formatted for New Horizons science team members to analyze. Raw and calibrated data, along with various ancillary files (such as documents describing the pipeline process or the science instruments) will also be archived in NASA's Planetary Data System.

Planetary Pioneers

New Horizons will join an elite class of spacecraft when it becomes Pluto's first visitor. The United States has led the reconnaissance of the solar system, providing the first close-up look at every planet with a spacecraft.

Planet	Mission (year)
Mercury	Mariner 10 (1973)
Venus	Mariner 2 (1962)
Mars	Mariner 4 (1965)
Jupiter	Pioneer 10 (1973)
Saturn	Pioneer 11 (1979)
Uranus	Voyager 2 (1985)
Neptune	Voyager 2 (1989)

History Repeated: Mariner 4 made the first exploration of Mars on July 14, 1965 — exactly 50 years to the day before New Horizons' closest approach to Pluto!

Education and Communications

The New Horizons education and communications (E/C) program (formerly designated Education and Public Outreach, or E/PO) taps into the excitement of going to uncharted territories and visiting an unexplored planet in a new region of the solar system. With a range of hands-on, minds-on learning experiences and materials, the program provides unique opportunities for students, educators, museums, science centers, Web surfers and other members of the public to ride along on the first mission to Pluto and the Kuiper Belt.

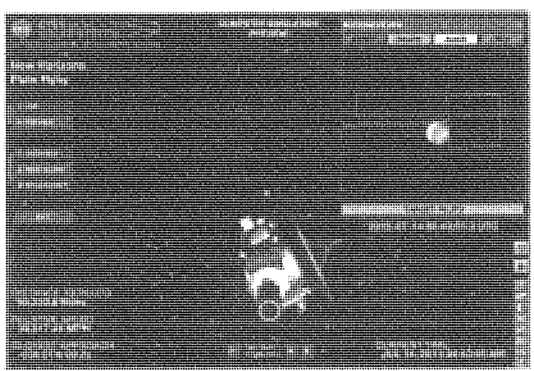
The E/C program includes a variety of formal lesson plans and learning materials — based on New Horizons science and engineering goals, and aligned with National Research Council's National Science Education Standards — that are helping students in grades K-12 learn more about science, technology, engineering and mathematics. The learning doesn't stop in high school: college students have designed and built an actual flight instrument on New Horizons — the Student Dust Counter — and held internships with the spacecraft integration and test team. Many of the New Horizons higher education initiatives focus on students from historically black colleges and universities and minority serving institutions.

New Horizons E/C programs go beyond the classroom, from a unique chance for people to send their names to Pluto on board the New Horizons spacecraft before launch, to opportunities for the public to access milestone events, mission data, and general information in places such as museums, science centers and libraries, TV and the Web — and, in 2015, through interactive "Plutopalooza" road shows.

For more information on the E/C team and New Horizons educational materials, visit: http://pluto.jhuapl.edu/Participate/.

Eyes on Pluto

You can't actually fly on New Horizons, of course, but NASA's Eyes on the Solar System program lets anyone with an Internet connection virtually ride along on the spacecraft's journey to Pluto and beyond. The Eyes on Pluto module, available to download from http://eyes.nasa.gov, includes simulated views of what New Horizons "sees," including the ability to run through the entire Pluto encounter!



Eyes on Pluto: A simulated ride through the New Horizons Pluto Encounter.

Real Science, Real Education

The Venetia Burney Student Dust Counter instrument, designed and built by students at the University of Colorado at Boulder, is a key part of the mission's E/C program. The device has been detecting dust grains produced by collisions between asteroids, comets and Kuiper Belt Objects during the long New Horizons' crossing of the solar system — but most notably, it is the first science instrument on a NASA planetary mission to be designed, built and operated by students.

With faculty supervision, the students have been distributing and archiving data from the instrument, and leading a comprehensive education and outreach effort to bring their results and experiences to classrooms of all grades. For a deeper look at the instrument and the team that developed it, visit http://lasp.colorado.edu/home/sdc/.

Encounter Timeline: Key Dates

June 2014: Ground-based and space-based Pluto system observation campaign started from Earth

July 2014: First optical navigation campaign began; trajectory correction maneuver on July 14

August 25, 2014: New Horizons crossed Neptune's orbit; took distant images of Neptune

December 6, 2014: New Horizons exited its last hibernation period before the Pluto encounter

January 2015: Ninth launch anniversary; Approach Phase 1 (distant encounter operations) began, optical navigation intensified, environmental monitoring with SWAP, PEPSSI and SDC began

April 2015: Approach Phase 2 began, New Horizons obtains best-ever images of Pluto

May 2015: Hazard observations began

June 2015: Approach Phase 3 begins

July 4, 2015: Last day to choose a "Safe Haven By Other Trajectory" path, or to keep the spacecraft on its original trajectory through the Pluto system

July 7, 2015: Core command load (for Pluto encounter) engages in spacecraft computer

July 12-13, 2015: "P-1" and "P-2" days; "fail safe" datasets (pre-flyby) sent back to Earth

July 14, 2015: Pluto system flyby; close approach to Pluto at 7:49 a.m. EDT

July 15, 2015: First-post flyby data returned; core command load disengages and Departure Phase 1 begins

August 2015: Departure Phase 2 begins

October 2015: Departure Phase 3 begins

October-November 2105: "Targeting" trajectory correction maneuver for possible Kuiper Belt Object encounter

November 2015: All browse data downloaded

January 2016: Pluto encounter formally ends

July 2016: Post-encounter calibrations completed

October-December 2016: Data playback of all encounter data completes

March 2017: Final Pluto Planetary Data System delivery

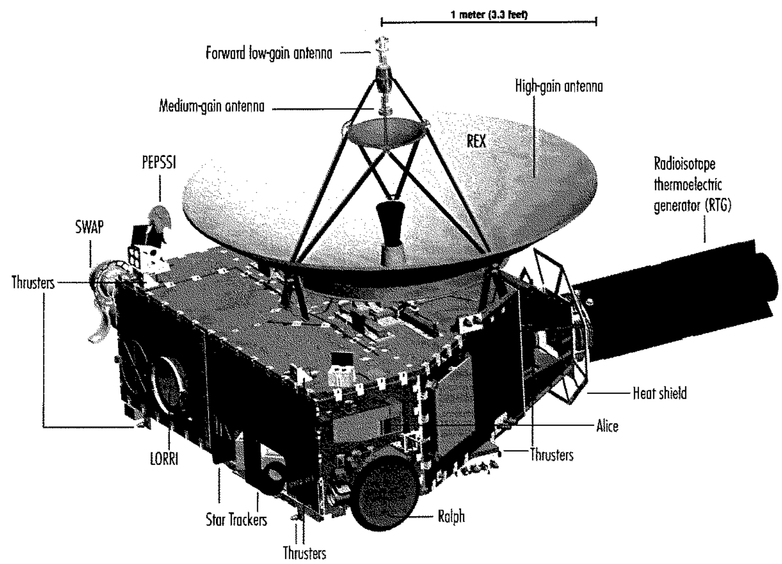
November 2017: Pluto Science Conference

Spacecraft Systems and Components

Designed and integrated at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland — with contributions from companies and institutions in the United States and abroad — New Horizons is a high-tech, robust, lightweight spacecraft designed to withstand a long, difficult journey to the solar system's coldest, darkest frontiers.

The New Horizons science payload was developed under direction of the Southwest Research Institute (SwRI), with instrument contributions from SwRI, APL, NASA's Goddard Space Flight Center, the University of Colorado, Stanford University and Ball Aerospace and Technologies Corporation. Fully fueled, the agile, piano-sized probe weighed 478 kilograms (1,054 pounds) at launch. Designed to operate on a limited power source — a single radioisotope thermoelectric generator — New Horizons needs less power than a pair of 100-watt light bulbs to complete its mission at Pluto. All of its operational subsystems include redundant backup systems.

On average, each of the seven science instruments uses between 2 and 10 watts — about the power of a night light — when turned on. The instruments send data to one of two onboard solid-state memory banks, where data is recorded for later playback to Earth. During normal operations, the spacecraft communicates with Earth through its 2.1-meter (83-inch) wide high-gain antenna. Smaller antennas provided limited, backup communications. And when the spacecraft was in hibernation through long stretches of its voyage, its computer was programmed to monitor its systems and report its status back to Earth with a specially coded, low-energy beacon signal.



New Horizons' "thermos bottle" design retains heat and keeps the spacecraft operating at room temperature without large heaters. Aside from protective covers on five instruments that were opened shortly after launch, and one small protective cover opened after the Jupiter encounter, New Horizons has no deployable mechanisms or scanning platforms. It does have backup devices for all major electronics, its star-tracking navigation cameras and data recorders.

New Horizons operated mostly in a spin-stabilized mode during the eight-year cruise between Jupiter and Pluto, and also in a three-axis "pointing" mode that allows for pointing or scanning instruments during calibrations and planetary encounters (like the Jupiter flyby and, of course, at Pluto). There are no reaction wheels on the spacecraft; small thrusters

in the propulsion system handle pointing, spinning and course corrections. The spacecraft navigates using onboard gyros, star trackers and Sun sensors. The spacecraft's high-gain antenna dish is linked to advanced electronics and shaped to receive even the faintest radio signals from home — a necessity when the mission's main target is 3 billion miles from Earth and round-trip transmission time is nine hours.

Structure

New Horizons' primary structure includes an aluminum central cylinder that supports honeycomb panels, supports the interface between the spacecraft and its (radioisotope thermoelectric generator) power source, houses the propellant tank, and serves as the payload adapter fitting that connects the spacecraft to the launch vehicle. Keeping mass down, the panels surrounding the central cylinder feature an aluminum honeycomb core with ultra-thin aluminum face sheets (about as thick as two pieces of paper). To keep it perfectly balanced for spinning operations, the spacecraft was weighed and then balanced with additional weights just before mounting on the launch vehicle.

Command and Data Handling

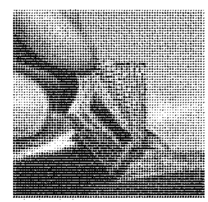
The command and data handling system — a radiation-hardened 12 megahertz Mongoose V processor guided by intricate flight software — is the spacecraft's "brain." The processor distributes operating commands to each subsystem, collects and processes instrument data, and sequences information sent back to Earth. It also runs advanced "autonomy" algorithms (essentially a remote pilot) that allow the spacecraft to check the status of each system and, if necessary, correct any problems, switch to backup systems or contact operators on Earth for help.

For data storage, New Horizons carries two low-power solid-state recorders (one backup) that can hold up to 8 gigabytes (64 gigabits) each. The main processor collects, compresses, reformats, sorts and stores science and housekeeping (telemetry) data on the recorder — similar to a flash memory card for a digital camera — for transmission to Earth through the telecommunications subsystem.

The Command and Data Handling processor, data recorder, power converters, Guidance and Control processor, radio science and tracking electronics, and interfaces between the processors and science instruments are housed in the Integrated Electronics Module (IEM), a space- and weight-saving device that combines the spacecraft's core avionics in a single box. New Horizons carries a redundant IEM as a backup.

Thermal Control

New Horizons is designed to retain heat like a thermos bottle. The spacecraft is covered in lightweight, gold-colored, multilayered thermal insulation blankets, which hold in heat from operating electronics to keep the spacecraft warm. Heat from the electronics has kept the spacecraft operating at between 10-30 degrees Celsius (about 50-85 degrees Fahrenheit) throughout the journey.


New Horizons thermal blanketing: an inside look.

New Horizons' sophisticated, automated heating system monitors power levels inside the craft to make sure the electronics are running at enough wattage to maintain safe temperatures. Any drop below that operating level (about 150 watts) and it will activate small heaters around the craft to make up the difference. When the spacecraft was closer to Earth and the Sun, louvers (essentially heat vents) on the craft opened when internal temperatures were too high.

The thermal blanketing — 18 layers of Dacron mesh cloth sandwiched between aluminized Mylar and Kapton film — also helps to protect the craft from micrometeorites and other hazardous debris.

Propulsion

The propulsion system on New Horizons is used for course corrections and for pointing the spacecraft. It is not needed to speed the spacecraft to Pluto; that was done entirely by the launch vehicle, with a boost from Jupiter's gravity.

The New Horizons propulsion system includes 16 small hydrazine-propellant thrusters mounted across the spacecraft in eight locations, a fuel tank, and associated distribution plumbing. Four thrusters that each provide 4.4 newtons (1 pound) are used mostly for course corrections. Operators also employ 12 smaller thrusters — providing 0.8 newtons (about 3 ounces) of thrust each — to point, spin up and spin down the spacecraft. Eight of the 16 thrusters aboard New Horizons are considered the primary set; the other eight comprise the backup (redundant) set.

At launch, the spacecraft carried 77 kilograms (170 pounds) of hydrazine, stored in a lightweight titanium tank. More than half of the fuel remains, enough for Pluto encounter, Pluto data downlink, and a robust extended KBO mission. Helium gas pushes fuel through the system to the thrusters. Using a Jupiter gravity assist, along with the fact that New Horizons does not need to slow down enough to enter orbit around Pluto, reduced the amount of propellant needed for the mission.

Guidance and Control

New Horizons must be oriented in a particular direction to collect data with its scientific instruments, communicate with Earth, or maneuver through space.

Attitude determination — knowing which direction New Horizons is facing — is performed using star-tracking cameras, Inertial Measurement Units (containing sophisticated gyroscopes and accelerometers that measure rotation and horizontal/vertical motion), and digital solar sensors. Attitude control for the spacecraft — whether in a steady, three-axis pointing mode or in a spin-stabilized mode — is accomplished using thrusters.

The IMUs and star trackers provide constant positional information to the spacecraft's Guidance and Control processor, which like the Command and Data Handling processor is a 12-MHz Mongoose V. New Horizons carries two copies of each of these units for redundancy. The star-tracking cameras store a map of about 3,000 stars; 10 times per second one of the cameras snaps a wide-angle picture of space, compares the locations of the stars to its onboard map, and calculates the spacecraft's orientation. The IMU feeds motion information 100 times a second. If data shows New Horizons is outside a predetermined position, small hydrazine thrusters will fire to re-orient the spacecraft. The Sun sensors back up the star trackers; in an emergency they would find and point New Horizons toward the Sun (with Earth nearby) if the other sensors couldn't find home.

Operators use thrusters to maneuver the spacecraft, which has no internal reaction wheels. Its smaller thrusters are used for fine pointing; thrusters that are approximately five times more powerful are used during the trajectory course maneuvers that guide New Horizons toward its targets. New Horizons spins — typically at 5 revolutions per minute — during trajectory-correction maneuvers and long radio contacts with Earth, as well as while it "hibernated" during long cruise periods. Operators steady and point the spacecraft during science observations and instrument-system checkouts.

Communications

New Horizons' X-band communications system is the spacecraft's link to Earth, returning science data, exchanging commands and status information, and allowing for precise radiometric tracking through NASA's Deep Space Network of antenna stations.

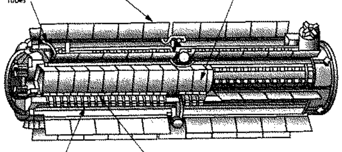
The system includes two broad-beam, low-gain antennas on opposite sides of the spacecraft, used mostly for near-Earth communications; as well as a 30-centimeter (12-inch) diameter medium-gain dish antenna and a large, 2.1-meter (83-inch) diameter high-gain dish antenna. The antenna assembly on the spacecraft's top deck consists of the high, medium, and forward low-gain antennas; this stacked design provided a clear field of view for the low-gain antenna and structural support for the high and medium-gain dishes. Operators aim the antennas by turning the spacecraft toward Earth. The high-gain beam is only 0.3 degrees wide, so it must point directly at Earth. The wider medium-gain beam (14 degrees) is used in conditions when the pointing might not be as accurate. All antennas have Right Hand Circular and Left Hand Circular polarization feeds.

Data rates depend on spacecraft distance, the power used to send the data and the size of the antenna on the ground. For most of the mission, New Horizons has used its high-gain antenna to exchange data with the Deep Space Network's largest antennas, 70 meters across. At Pluto, because New Horizons is about 3 billion miles from Earth and radio signals take more than four hours to reach the spacecraft, it can send information at about 2,000 bits per second. It will take 16 months to send the full set of Pluto encounter science data back to Earth.

New Horizons is flying the most advanced digital receiver ever used for deep space communications. Advances include regenerative ranging and low power — the receiver consumes 66% less power than earlier deep-space receivers. The Radio Science Experiment (REX) that will be used to examine Pluto's atmosphere is also integrated into the communications subsystem. The entire telecom system on New Horizons is redundant, with two of everything except the high gain antenna structure itself.

Power

New Horizons' electrical power comes from a single radioisotope thermoelectric generator (RTG), shown below, which provides power through the natural radioactive decay of plutonium dioxide fuel. The New Horizons RTG, provided by the U.S. Department of Energy, carries approximately 11 kilograms (24 pounds) of plutonium dioxide. Onboard systems manage the spacecraft's power consumption so it doesn't exceed the steady output from the RTG, which has decreased by about 3.3 watts per year since launch.



Typical of RTG-based systems, and as on past outer-planet missions, New Horizons does not have a battery for storing power.

At the start of the mission, the RTG supplied approximately 245 watts (at 30 volts of direct current) — the spacecraft's shunt regulator unit maintains a steady input from the RTG and dissipates power the spacecraft cannot use at a given time. Now, more than nine years after launch, that supply has decreased to just under 202 watts, so New Horizons must carefully distribute its power by cycling science instruments on and off during the encounter.

The spacecraft's fully redundant Power Distribution Unit (PDU) — with 96 connectors and more than 3,200 wires — efficiently moves power through the spacecraft's vital systems and science instruments.

Many scientific instruments work better when they are cold; that's one reason why they are located opposite the RTG on the spacecraft. New Horizons also has a heat shield around the base of the RTG to avoid a direct line of sight from the instruments to the RTG. These design features help avoid any interference from the RTG with scientific measurements.

RTGs have powered some of NASA's greatest voyages; read more at: http://rps.nasa.gov.

Mementos to Pluto — and Beyond

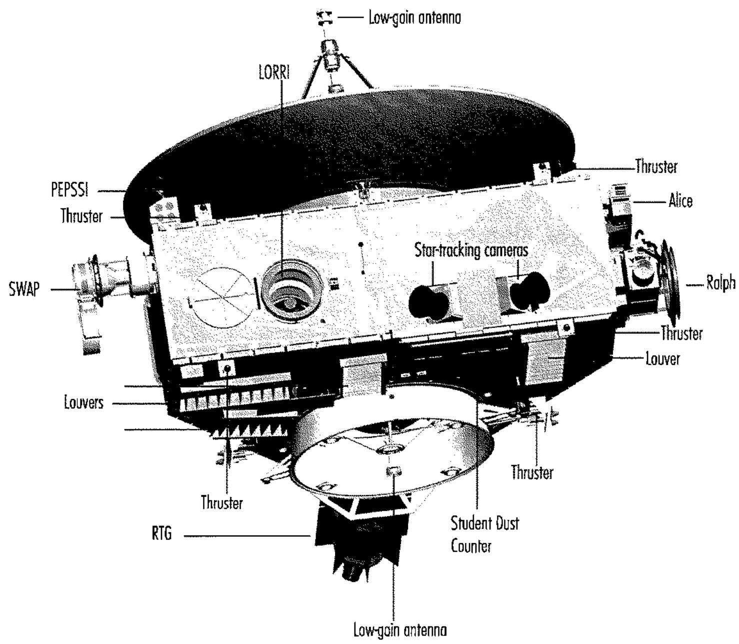
Along with the advanced instruments and systems that enable New Horizons' historic exploration of Pluto and the Kuiper Belt, the spacecraft carries nine mementos:

- A portion of Pluto discoverer Clyde Tombaugh's ashes and an inscription
- A "Send Your Name to Pluto" CD-ROM with more than 434,000 names of people who wanted to participate in this great journey of exploration
- A CD-ROM with project personnel pictures and messages
- A Florida state quarter, representing where New Horizons was launched
- A Maryland state quarter, representing where New Horizons was built
- A cutout piece of the historic SpaceShipOne and an inscription
- Two U.S. flags
- The 1991 U.S. stamp proclaiming, "Pluto: Not Yet Explored"

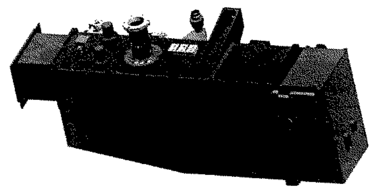
Science Instruments

New Horizons packs the most advanced suite of cameras and spectrometers ever sent on a first reconnaissance mission. The New Horizons science payload consists of seven instruments — three optical instruments, two plasma instruments, a dust sensor and a radio science receiver/radiometer. This payload was designed to investigate the global geology, surface composition and temperature, and the atmospheric pressure, temperature, composition, and escape rate from Pluto and its largest moon.

The payload is incredibly power efficient — with the instruments collectively drawing less than 28 watts — and represents a degree of miniaturization that is unprecedented in planetary exploration. The instruments were designed specifically to handle the cold conditions and low light levels at Pluto and in the Kuiper Belt beyond.



Alice



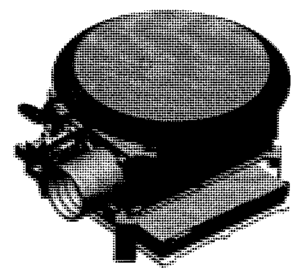
Mass: 4.5 kilograms (9.9 pounds)
Average Power: 4.4 watts
Development: Southwest Research Institute
Principal Investigator: Alan Stern, Southwest Research Institute
Purpose: Study atmospheric composition and structure

Alice is a sensitive ultraviolet imaging spectrometer designed to probe the composition and structure of Pluto's dynamic atmosphere. Where a spectrometer separates light into its constituent wavelengths (like a prism), an "imaging spectrometer" both separates the different wavelengths of light and produces an image of the target at each wavelength. Alice's spectroscopic range extends across both extreme and far-ultraviolet wavelengths from approximately 500 to 1,800 Angstroms. The instrument will detect a variety of important atomic and molecular species in Pluto's atmosphere, and determine their relative abundances, giving scientists the first complete picture of Pluto's atmospheric composition. Alice will search for an ionosphere around Pluto and an atmosphere around Pluto's largest moon, Charon. It will also probe the density of Pluto's atmosphere, and the atmospheric temperature of Pluto, both as a function of altitude.

Alice consists of a compact telescope, a spectrograph, and a sensitive electronic detector with 1,024 spectral channels at each of 32 separate spatial locations in its long, rectangular field of view. Alice has two modes of operation: an "airglow" mode that measures ultraviolet emissions from atmospheric constituents, and an "occultation" mode, where it views the Sun or a bright star through an atmosphere and detects atmospheric constituents by the amount of sunlight they absorb. Absorption of sunlight by Pluto's atmosphere will show up as characteristic "dips" and "edges" in the ultraviolet part of the spectrum of light that Alice measures. This technique is a powerful method for measuring even traces of atmospheric gas.

A first-generation version of New Horizons' Alice (smaller and a bit less sophisticated) is flying aboard the European Space Agency's Rosetta spacecraft, examining the surface of comet 67P/Churyumov-Gerasimenko and studying its escaping atmosphere and complex surface. Other Alice instruments are in flight aboard NASA's Lunar Reconnaissance Orbiter and Juno Spacecraft.

Ralph



Mass: 10.3 kilograms (22.7 pounds)
Average Power: 6.3 watts
Development: Ball Aerospace and Technologies Corporation, NASA Goddard Space Flight Center, Southwest Research Institute
Principal Investigator: Alan Stern, Southwest Research Institute
Purpose: Study surface geology and morphology; obtain surface composition and surface temperature maps

Ralph is the main "eyes" of New Horizons and is charged with making the maps that show what Pluto, its moons, and (potentially) other Kuiper Belt Objects look like. (The instrument is so named because it's coupled with an ultraviolet spectrometer called Alice in the New Horizons remote-sensing package — a reference familiar to fans of "The Honeymooners" TV show.)

Ralph consists of three panchromatic (black-and-white) and four color imagers inside its Multispectral Visible Imaging Camera (MVIC), as well as an infrared compositional mapping spectrometer called the Linear Etalon Imaging Spectral Array (LEISA). LEISA is an advanced, miniaturized short-wavelength infrared (1.25-2.50 micron) spectrometer provided by NASA's Goddard Space Flight Center. MVIC operates over the bandpass from 0.4 to 0.95 microns. Ralph's suite of eight detectors — seven charge-coupled devices (CCDs) like those found in a digital camera, and a single infrared array detector — are fed by a single, sensitive magnifying telescope with a resolution more than 10 times better than the human eye can see. The entire package operates on less than half the wattage of a nightlight.

Ralph will take images twice daily as New Horizons approaches, flies past and then looks back at the Pluto system. Ultimately, MVIC will map landforms in black-and-white and color with a best resolution of about 250 meters (820 feet) per pixel, take stereo images to determine surface topography, and help scientists refine the radii and orbits of Pluto and

its moons. It will aid the search for clouds and hazes in Pluto's atmosphere, and for rings and additional satellites around Pluto. It will also obtain images of Pluto's night side, illuminated by "Charon-light." At the same time, LEISA will map the amounts of nitrogen, methane, carbon monoxide, and frozen water and other materials, including organic compounds, across the sunlit surfaces of Pluto and its moons.

LEISA will also let scientists map surface temperatures across Pluto and Charon by sensing the temperature diagnostic spectral features of frozen nitrogen, water and carbon monoxide. And Pluto is so far from the Sun that Ralph must work with light levels 1,000 times fainter than daylight at Earth — or 400 times fainter than conditions Mars probes face — so it is incredibly sensitive.

Radio Science Experiment (REX)

Mass: 100 grams (3.5 ounces)
Average Power: 2.1 watts
Development: Johns Hopkins University Applied Physics Laboratory, Stanford University
Principal Investigators: Len Tyler and Ivan Linscott, Stanford University
Purpose: Measure atmospheric temperature and pressure (down to the surface); measure density of the ionosphere; search for atmospheres around Charon and (possibly) other KBOs; determine the mass and density of Pluto and Charon; determine the surface day and night temperatures.

REX consists only of a miniaturized printed circuit board containing sophisticated signal-processing electronics integrated into the New Horizons telecommunications system. Because the telecom system is redundant within New Horizons, the spacecraft carries two copies of REX. Both can be used simultaneously to improve the data return from the radio science experiment.

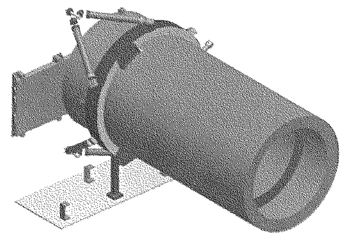
REX will use an occultation technique to probe Pluto's atmosphere and to search for an atmosphere around Charon. After New Horizons flies by Pluto, its 2.1-meter (83-inch) dish antenna will point back to Earth. On Earth, powerful transmitters in NASA's largest Deep Space Network antennas will beam radio signals to the spacecraft as it passes behind Pluto. The radio waves will bend according to the average molecular weight of gas in the atmosphere and the atmospheric temperature. The same phenomenon could happen at Charon if the large moon has a substantial atmosphere, though Earth-based studies indicate this is unlikely.

Space missions typically conduct this type of experiment by sending a signal from the spacecraft through a planet's atmosphere and back to Earth. (This is called a "downlink" radio experiment.) New Horizons will be the first to use a signal from Earth — the spacecraft will be so far from home and moving so quickly past Pluto and Charon that only a large, ground-based antenna can provide a strong enough signal. This new technique, called an "uplink" radio experiment, is an important advance beyond previous outer planet missions.

REX will also measure the weak radio emissions from Pluto and Charon. Scientists will use that data to derive accurate day-side and night-side temperature measurements. Also, by using REX to track slight changes in the spacecraft's path, scientists will measure the masses and densities of Pluto and Charon and possibly the masses of additional Kuiper Belt Objects in order to develop models of the interior of each body. By timing the length of the radio occultations of Pluto and Charon, REX will also yield improved radii measurements for each body and will attempt to detect radar signals from Earth that reflect off Pluto during the flyby to probe Pluto's surface properties.

Long Range Reconnaissance Imager (LORRI)

Mass: 8.8 kilograms (19.4 pounds)
Average Power: 5.8 watts
Development: Johns Hopkins University Applied Physics Laboratory
Principal Investigator: Andy Cheng, Applied Physics Laboratory
Purpose: Study geology; provide high-resolution approach and highest-resolution encounter images



LORRI, the "eagle eyes" of New Horizons, is a panchromatic high-magnification imager, consisting of a telescope with an 8.2-inch (20.8-centimeter) aperture that focuses visible light onto a charge-coupled device (CCD). It's essentially a digital camera with a large telephoto telescope — only fortified to operate in the cold, hostile environs near Pluto.

As the encounter began, LORRI images were New Horizons' first of the Pluto system, starting in January 2015. At the time, Pluto and its moons resembled little more than bright dots, but these system-wide views have been helping navigators keep the spacecraft on course and helping scientists refine their orbit calculations of Pluto and its moons.

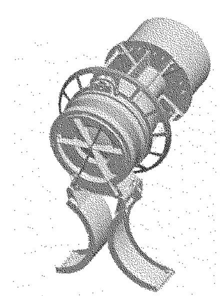
At closest approach, LORRI will image select sections of Pluto's sunlit surface at football-field-size resolution, resolving features as small as 70 meters across. Three days before, it will map the "far side" hemisphere of Pluto.

This range of images will give scientists an unprecedented look at the geology on Pluto, Charon, and additional Kuiper Belt Objects — including the number and size of craters on each surface, revealing the history of impacting objects in that distant region. LORRI will also yield important information on the history of Pluto's surface, search for activity such as geysers, and look for hazes in Pluto's atmosphere. LORRI will also provide the highest resolution images of any Kuiper Belt Objects New Horizons would fly by in an extended mission.

LORRI has no color filters or moving parts — operators will take images by pointing the LORRI side of the spacecraft directly at their target. The instrument's innovative silicon carbide construction will keep its mirrors focused through the extreme temperature dips New Horizons will experience on the way to, through and past the Pluto system.

Solar Wind at Pluto (SWAP)

Mass: 3.3 kilograms (7.3 pounds)
Average Power: 2.3 watts
Development: Southwest Research Institute
Principal Investigator: David McComas, Southwest Research Institute
Purpose: Study solar wind interactions and atmospheric escape



The SWAP instrument will measure interactions of Pluto with the solar wind — the high-speed stream of charged particles flowing from the Sun. The incredible distance of Pluto from the Sun required the SWAP team to build the largest-aperture instrument ever used to measure the solar wind.

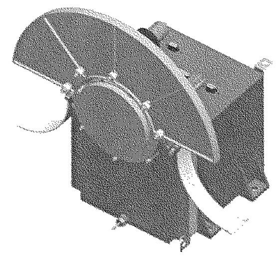
Pluto's small gravitational acceleration (approximately 1/16 of Earth's gravity) leads scientists to think that about 75 kilograms (165 pounds) of material escape its atmosphere every second. The atmospheric gases that escape Pluto's weak gravity leave the planet as neutral atoms and molecules. These atoms and molecules are ionized by ultraviolet sunlight (similar to Earth's upper atmosphere and ionosphere). Once they become electrically charged, the ions and electrons become "picked up" and are carried away by the solar wind. In the process, these pickup ions gain substantial energy (thousands of electron-volts). This energy comes from the solar wind, which is correspondingly slowed down and diverted around Pluto. SWAP measures low-energy interactions, such as those caused by the solar wind. By measuring how and where the solar wind is blocked by Pluto's escaping atmosphere, SWAP will determine the escape rate of atmospheric material from Pluto.

At the top of its energy range SWAP can detect some pickup ions (up to 6.5 kiloelectron volts, or keV). SWAP combines a retarding potential analyzer (RPA) with an electrostatic analyzer (ESA) to enable extremely fine, accurate energy measurements of the solar wind, allowing New Horizons to measure minute changes in solar wind speed. The amount of Pluto's atmosphere that escapes into space provides critical insights into the structure and destiny of the atmosphere itself.

Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI)

Mass: 1.5 kilograms (3.3 pounds)
Average Power: 2.5 watts
Development: Johns Hopkins University Applied Physics Laboratory
Principal Investigator: Ralph McNutt Jr., Applied Physics Laboratory
Purpose: Study the density and composition of energetic particles and plasmas resulting from the escape of Pluto's atmosphere

PEPSSI, the most compact, lowest-power directional energetic particle spectrometer flown on a space mission, will search for neutral atoms that escape Pluto's atmosphere and become charged by their interaction with the solar wind. It will detect the material that escapes from Pluto's atmosphere (such as molecular nitrogen, carbon monoxide and methane), which break up into ions and electrons after absorbing the Sun's ultraviolet light, and stream away from Pluto as "pickup" ions carried by the solar wind.



The instrument will likely get its first taste of Pluto's atmosphere when the planet is still millions of miles away. By using PEPSSI to count particles, and knowing how far New Horizons is from Pluto at a given time, scientists will be able to tell how quickly the planet's atmosphere is escaping and gain new information about the composition of the atmosphere.

PEPSSI is a classic "time-of-flight" particle instrument: particles enter the detector and knock other particles (electrons) from a thin foil; they zip toward another foil before hitting a solid-state detector. The instrument clocks the time between the foil collisions to tell the particle's speed (measuring its mass) and figures its total energy when it collides with the solid-state detector. From this, scientists can determine the composition of each particle. PEPSSI can measure energetic particles up to 1,000 kiloelectron volts (keV), many times more energetic than what SWAP can measure. Together the two instruments make a powerful combination for studying the particles and plasma in the Pluto system.

Venetia Burney Student Dust Counter (SDC)

Mass: 1.9 kilograms (4.2 pounds)
Average Power: 5 watts
Development: Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder
Principal Investigator: Mihaly Horanyi, University of Colorado at Boulder
Purpose: Measure concentration of dust particles across the outer solar system

Designed and built by students at the University of Colorado at Boulder, the SDC detects microscopic dust grains produced by collisions among asteroids, comets, and even Kuiper Belt Objects during New Horizons' long journey. Officially a New Horizons Education and Public Outreach project, SDC is the first science instrument on a NASA planetary mission to be designed, built and "flown" by students.

The SDC counts and measures the sizes of dust particles, producing information on the collision rates of such bodies in the outer solar system. SDC will also be used to search for dust in the Pluto system; such dust might be generated by collisions of tiny "impactors" on Pluto's small moons.

The instrument includes two major pieces: an 18-by-12-inch detector assembly, which is mounted on the outside of the spacecraft and exposed to the dust particles; and an electronics box inside the spacecraft that, when a hit occurs on the detector, deciphers the data and determines the mass and speed of the particle. Because no dust detector has ever flown beyond 18 astronomical units from the Sun (nearly 1.7 billion miles, about the distance from Uranus to the Sun), SDC data is giving scientists an unprecedented look at the sources and transport of dust in the solar system.

With faculty support, University of Colorado students have been distributing and archiving data from the instrument, and lead a comprehensive education and outreach effort to bring their results and experiences to classrooms of all grades.

In June 2006 the instrument was named for Venetia Burney, who at age 11 offered the name "Pluto" for the newly discovered ninth planet in 1930. Read about that here: http://pluto.jhuapl.edu/news_center/news/062906.php

Tech Specs

Visit http://pluto.jhuapl.edu/spacecraft/instruments.html for a chart of instrument technical specifications.

Fact:

The combined weight of all seven New Horizons instruments is less than just the primary camera (Imaging Science Subsystem) on NASA's Cassini Saturn orbiter.

New Horizons Management Team

Alan Stern, of the Southwest Research Institute's (SwRI) Boulder, Colorado, operation, leads the New Horizons mission as principal investigator. The Johns Hopkins University Applied Physics Laboratory (APL), Laurel, Maryland, manages the New Horizons mission for the Science Mission Directorate, NASA Headquarters, Washington, D.C.

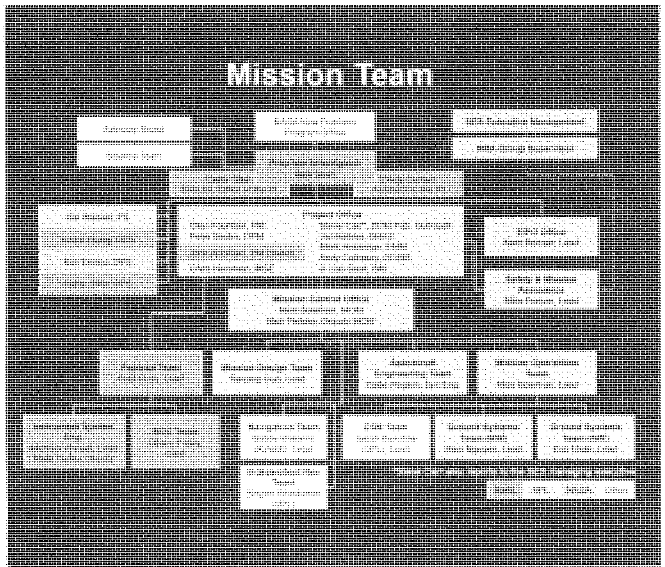
At NASA Headquarters, John Grunsfeld is the associate administrator for the Science Mission Directorate and Geoffrey Yoder is deputy associate administrator for the Science Mission Directorate. James Green is the director of the Planetary Science Division. Curt Neibur is the New Horizons program scientist and Adriana Ocampo is the New Horizons program executive. At NASA's Marshall Space Flight Center, Hunstville, Alabama, Allen Bacskay is the New Frontiers program manager and James Lee is New Horizons mission manager.

At APL, Glen Fountain is the New Horizons project manager, Peter Bedini is deputy project manager and Harold Weaver is New Horizons project scientist. Mark Holdridge is encounter mission manager, Alice Bowman is mission operations manager, Chris Hersman is mission systems engineer, Yanping Guo is mission design team lead and Kerri Beisser is education and communications manager. Michael Ryschkewitsch is the head of the APL Space Exploration Sector and Ralph Semmel is the director of the Applied Physics Laboratory.

At SwRI in Boulder, Leslie Young and Cathy Olkin are New Horizons deputy project scientists, and Tiffany Finley is the Tombaugh Science Operations Center team lead. At SwRI in San Antonio, John Andrews is New Horizons project manager. James Burch is vice president of the Space Science and Engineering Division and Adam Hamilton is the president of the Southwest Research Institute, San Antonio.

Kimberly Ennico, from NASA Ames Research Center, Mountain View, California, is a deputy project scientist. Bobby Williams leads the project navigation team at KinetX Inc., Simi Valley, California.

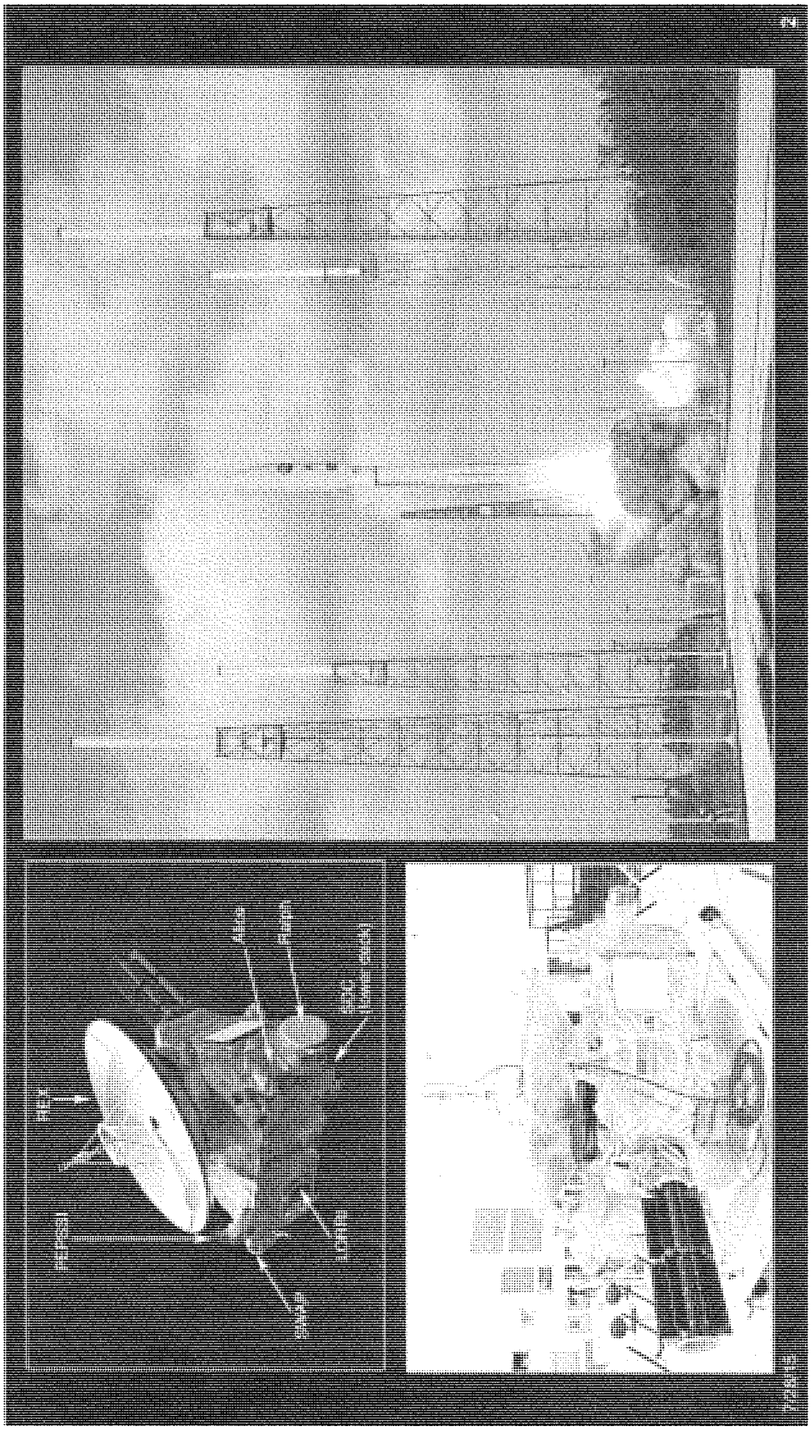
The New Horizons science team includes co-investigators from: Southwest Research Institute, Boulder, Colorado; Southwest Research Institute, San Antonio; Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland; University of Colorado, Boulder; Massachusetts Institute of Technology, Cambridge; NASA Jet Propulsion Laboratory, Pasadena, California; NASA Ames Research Center, Moffett Field, California; Lowell Observatory, Flagstaff, Arizona; Lunar and Planetary Institute, Houston; SETI Institute, Mountain View, California; Stanford University, Palo Alto, California; Washington University, St. Louis; Space Science Institute, Boulder, Colorado; Ball Aerospace, Boulder, Colorado; and George Mason University, Fairfax, Virginia.

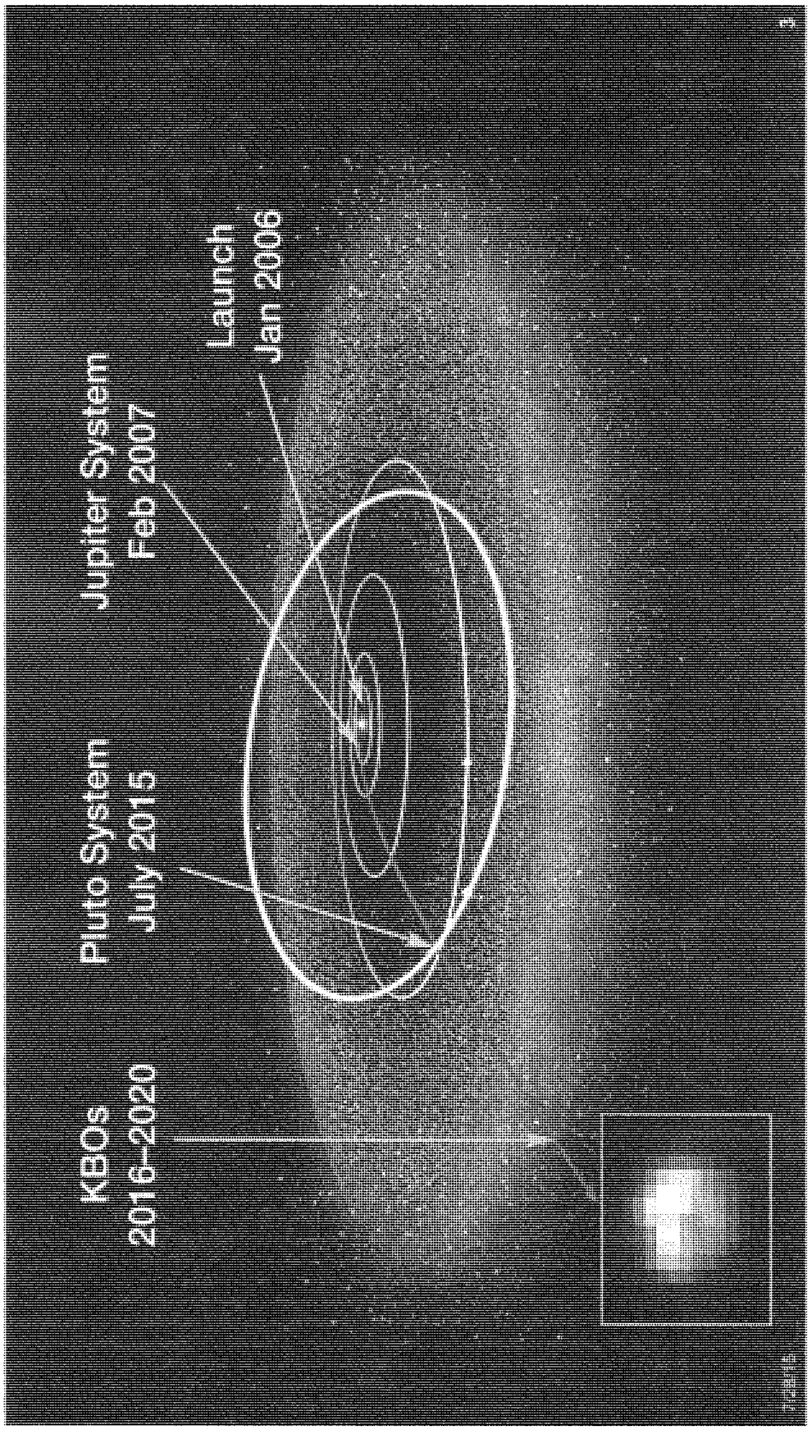

Mission Team

HOLD FOR RELEASE
UNTIL PRESENTED BY WITNESS
July 28, 2015

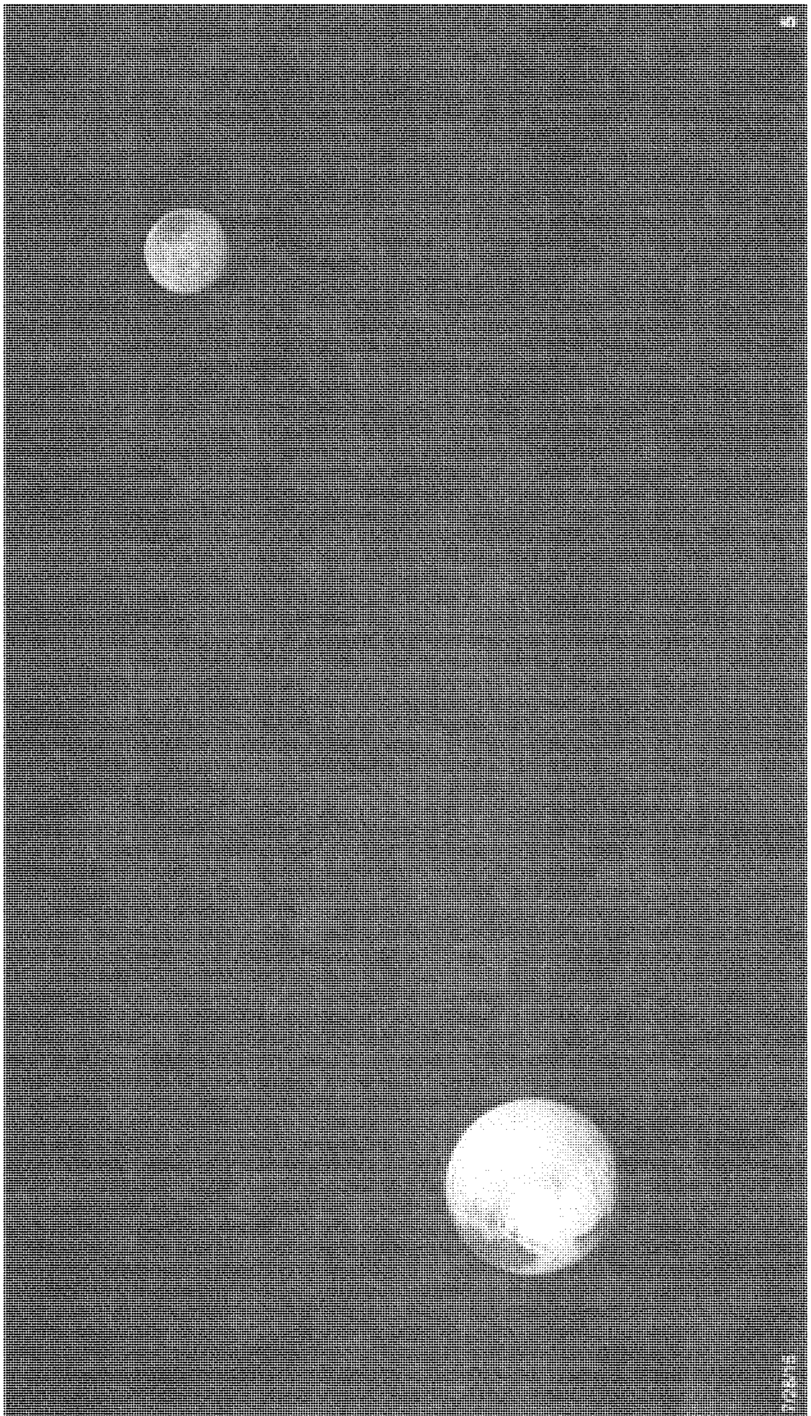
Testimony before the
Subcommittee on Space,
Committee on Science, Space and Technology
U.S House of Representatives

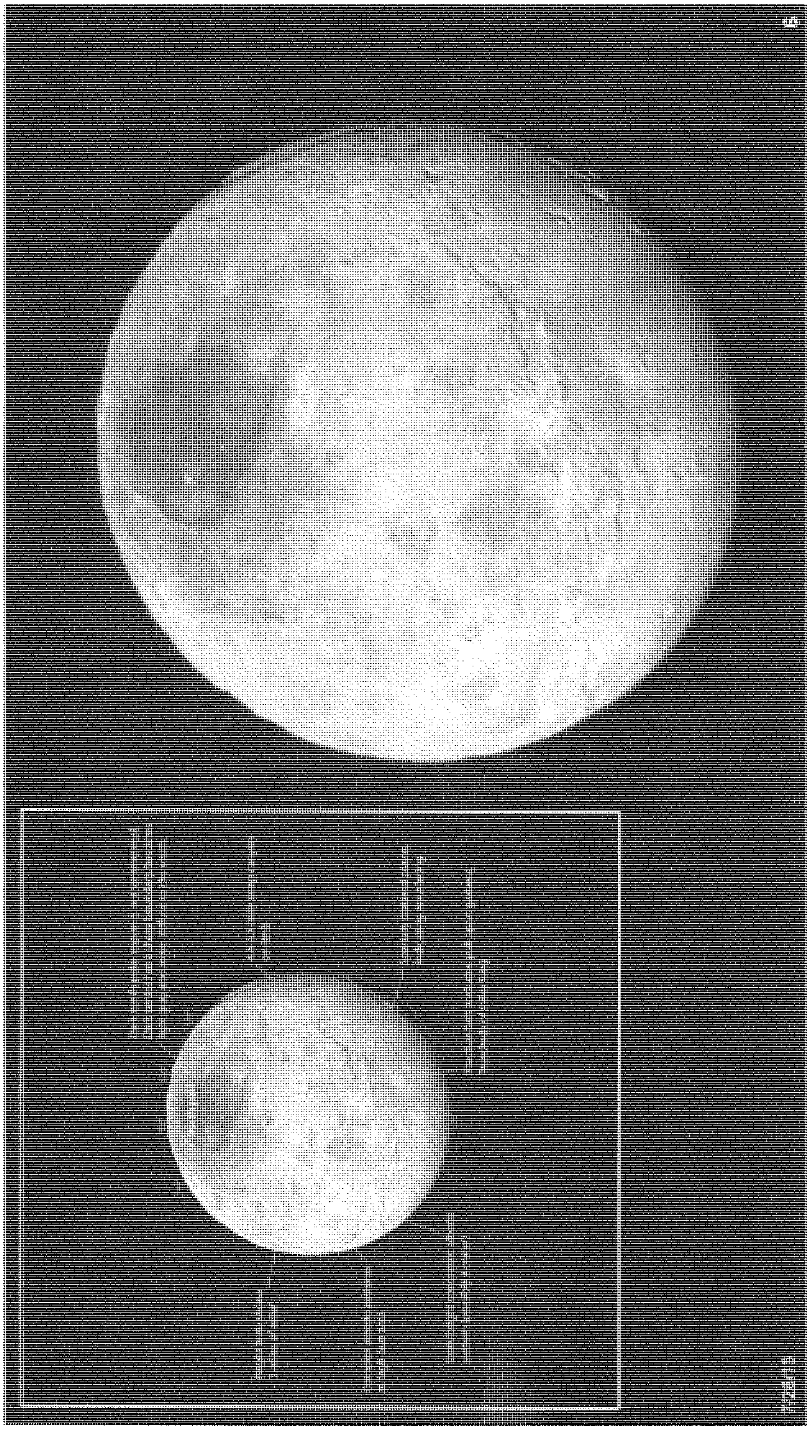
Statement of
Dr. S. Alan Stern
Principal Investigator
NASA's New Horizons Mission to the Pluto System
Southwest Research Institute, Boulder CO

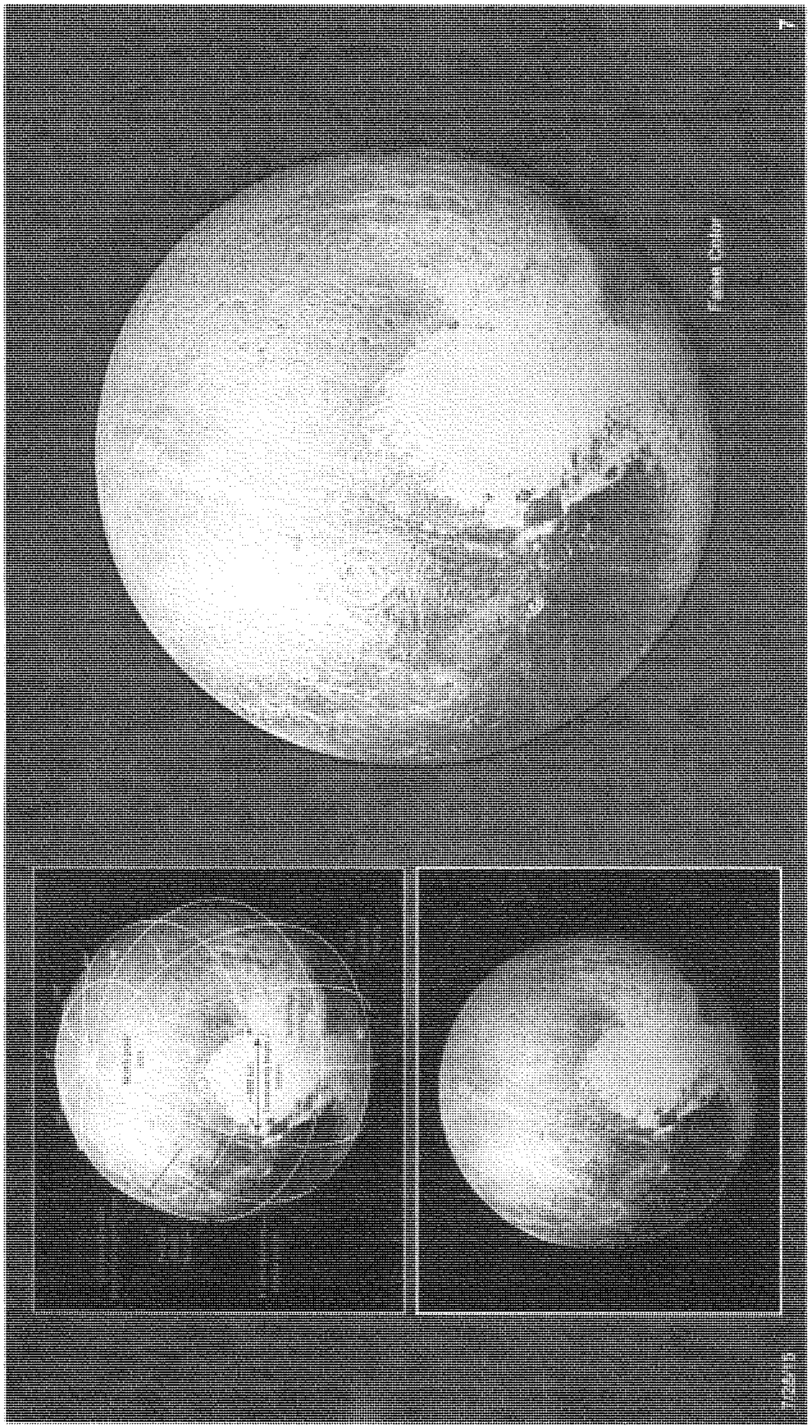



KBOs
2016–2020
Pluto System
July 2015
Jupiter System
Feb 2007
Launch
Jan 2006


PLUTO
EXPLORED



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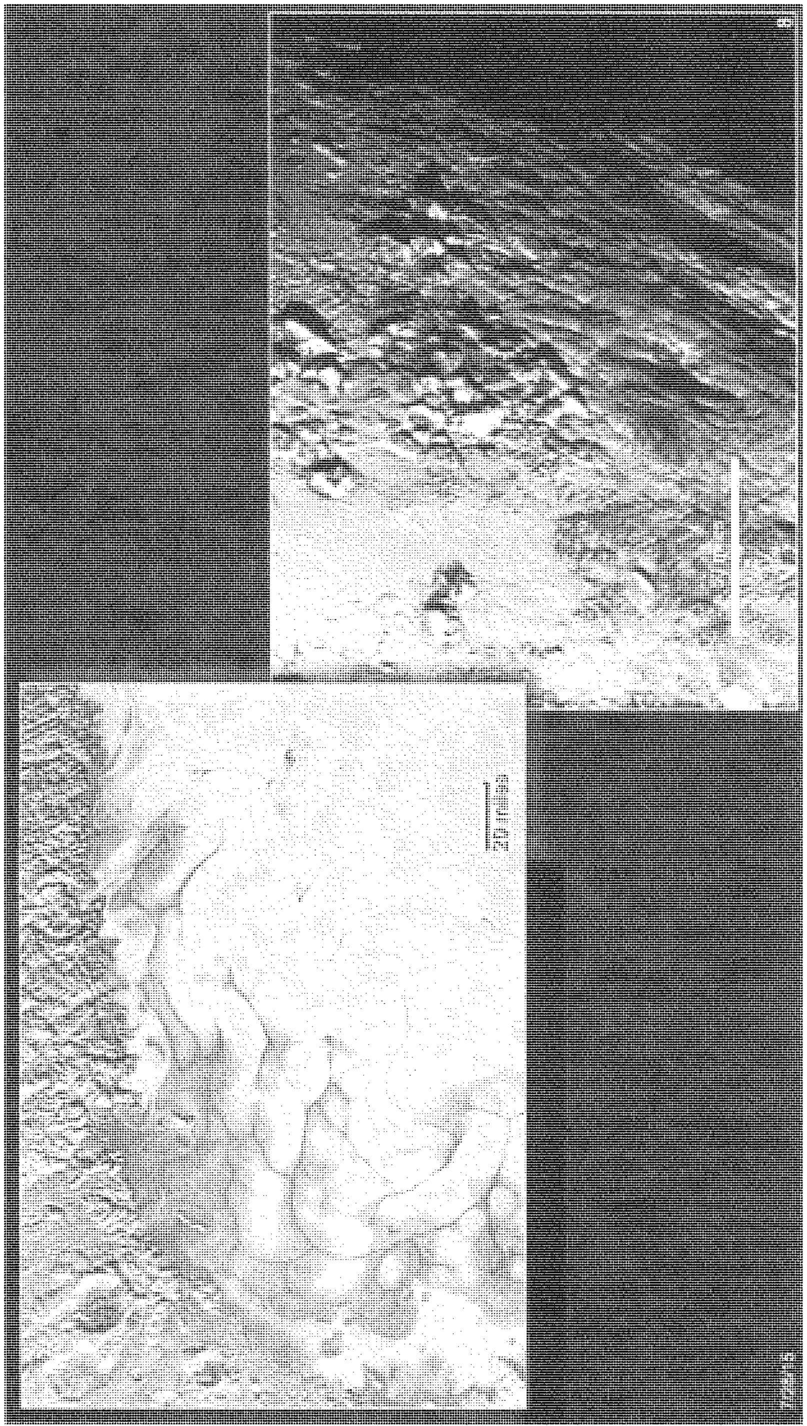

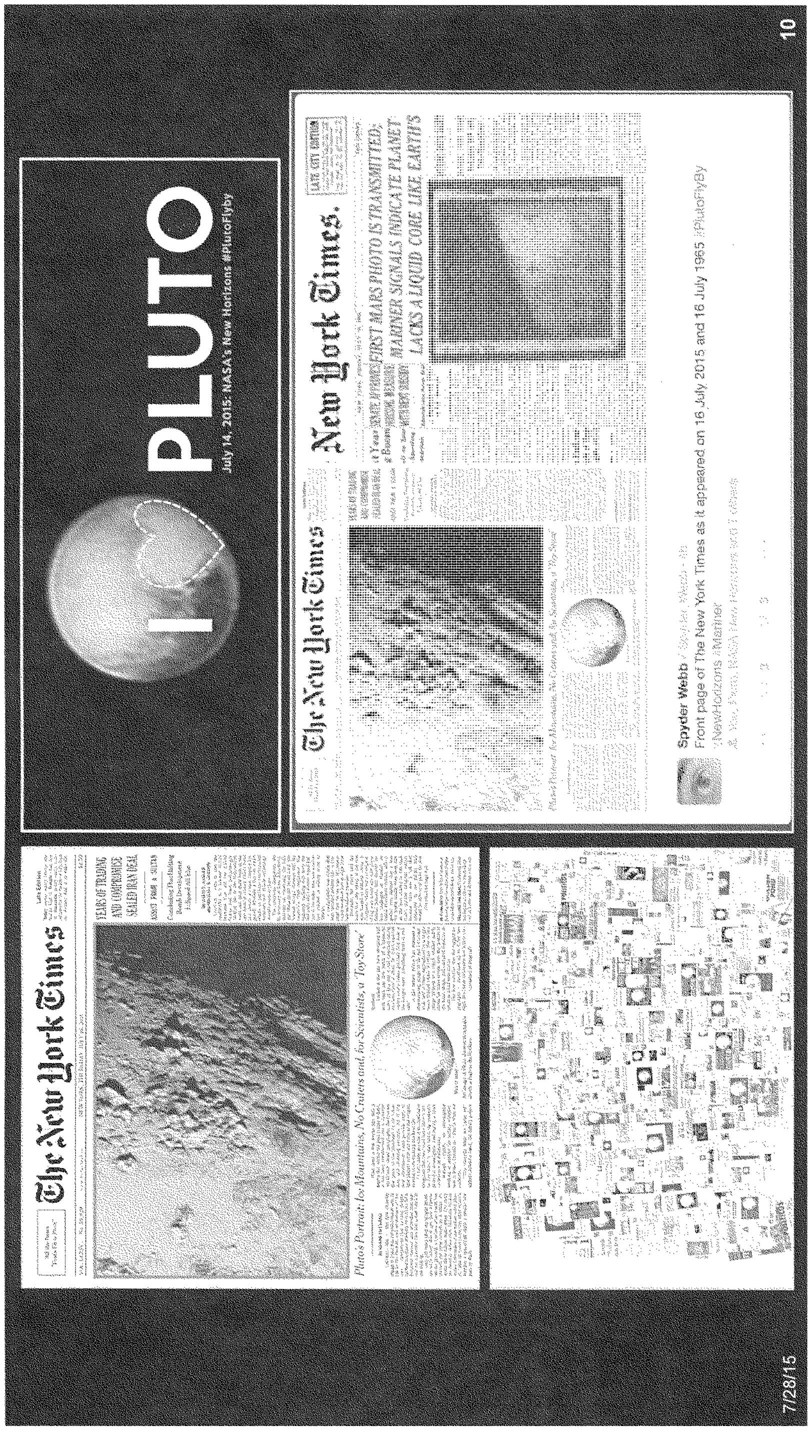
The New York Times
Pluto's Portrait: No Mountains, No Craters and, for Scientists, a 'Toy Story'
I PLUTO
July 14, 2015: NASA's New Horizons #PlutoFlyby
New York Times.
FIRST MARS PHOTO IS TRANSMITTED; MARINER SIGNALS INDICATE PLANET LACKS A LIQUID CORE LIKE EARTH'S
Spyder Webb
Front page of The New York Times as it appeared on 16 July 2015 and 16 July 1965 #PlutoFlyBy
#NewHorizons #Mariner
7/28/15
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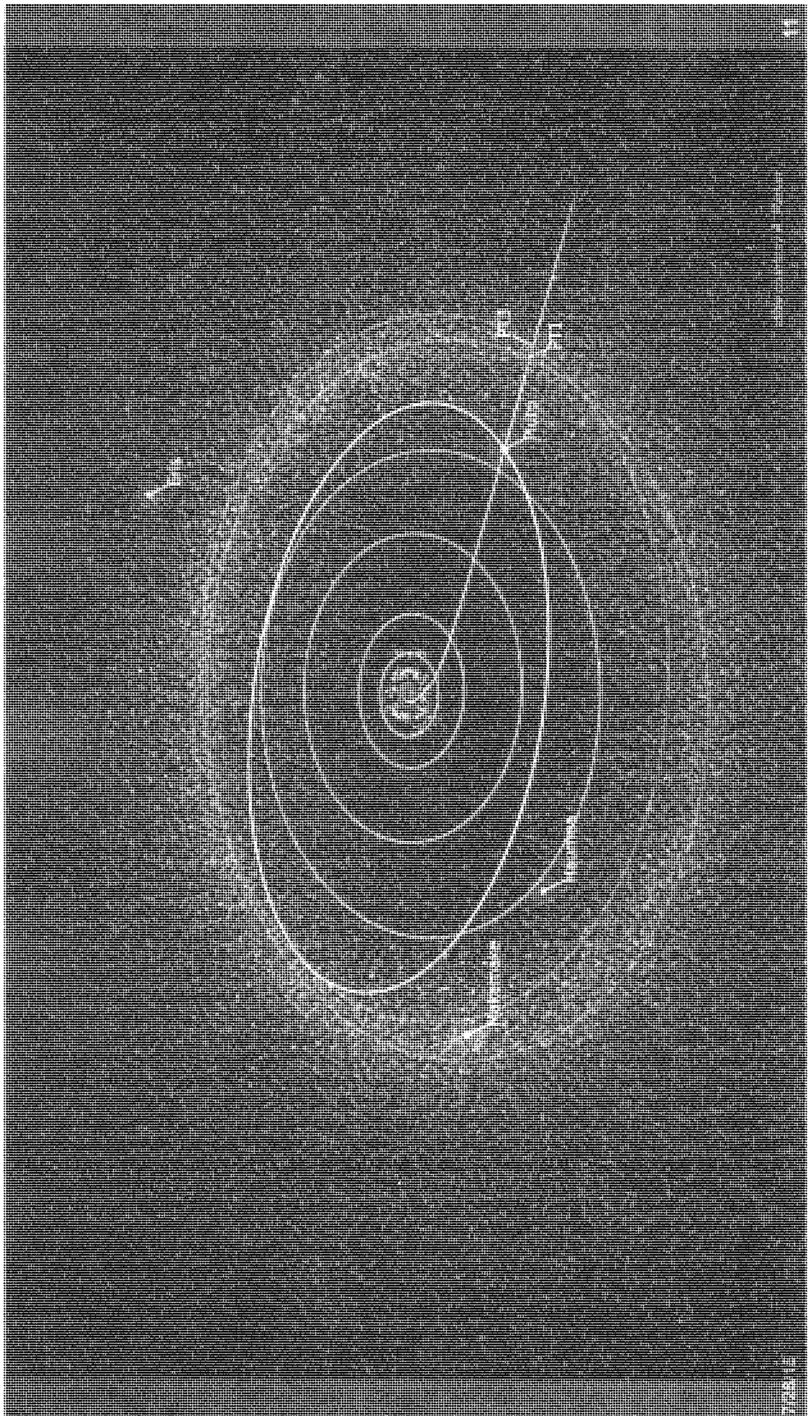
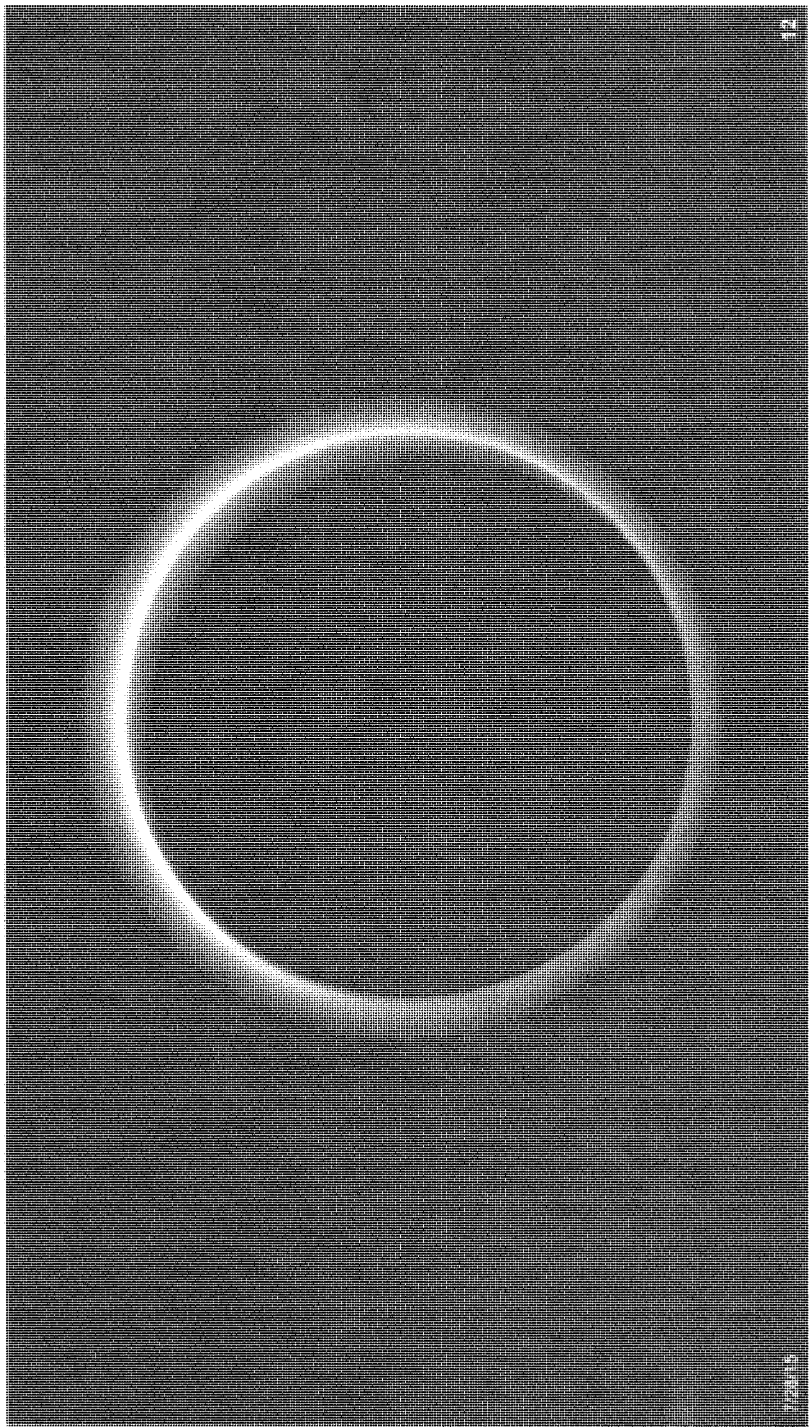
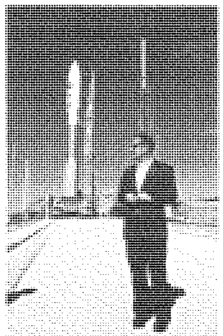




S. Alan Stern



Dr. Alan Stern is a planetary scientist, space program executive, aerospace consultant, and author. He leads NASA's New Horizons mission to the Pluto system and the Kuiper Belt.

In 2007, he was named to the Time 100 and was appointed NASA's chief of all science missions. Since 2009, he has been an Associate Vice President and Special Assistant to the President at the Southwest Research Institute. Additionally, from 2008-2012 he served on the board of directors of the Challenger Center for Space Science Education, and as the Chief Scientist and Mission Architect for Moon Express from 2010-2013. From 2011-2013 he served as the Director of the Florida Space Institute. Dr. Stern currently serves as the chief scientist of World View, a near-space ballooning company, and of the Florida Space Institute.

In 2007 and 2008, Dr. Stern served as NASA's chief of all space and Earth science programs, directing a $4.4B organization with 93 separate flight missions and a program of over 3,000 research grants. During his NASA tenure, a record 10 major new flight projects were started and deep reforms of NASA's scientific research and the education and public outreach programs were put in place. His tenure was notable for an emphasis on cost control in NASA flight missions that resulted in a 63% decrease in cost overruns.

Since 2008 Dr. Stern has had his own aerospace consulting practice. His current and former consulting clients include Jeff Bezos's Blue Origin, Richard Branson's Virgin Galactic, Naveen Jain's Moon Express Google Lunar X-Prize team, Ball Aerospace, Paragon Space Development Corporation, the NASTAR Center, Embry Riddle Aeronautical University, and the Johns Hopkins University.

Dr. Stern is also the CEO of two small corporations—Uwingu and The Golden Spike Company—and serves on the board of directors of the Commercial Spaceflight Federation.
Dr. Stern is the Principal Investigator (PI) of NASA's $723M New Horizon's mission to reconnoiter Pluto and the Kuiper Belt. New Horizons launched in 2006 and arrives at Pluto in July 2015. Dr. Stern is also the PI of two instruments aboard New Horizons, the Alice UV spectrometer and the Ralph Visible Imager/IR Spectrometer.

His career has taken him to numerous astronomical observatories, to the South Pole, and to the upper atmosphere aboard various high performance NASA aircraft including F/A-18 Hornets, F-104 Starfighters, KC-135 Zero-G, and WB-57 Canberras. He has been involved as a researcher in 24 suborbital, orbital, and planetary space missions, including 9 for which he was the mission principle investigator; and he has led the development of 8 scientific instruments for NASA space missions. In 1995, he was selected as a Space Shuttle mission specialist finalist, and in 1996 he was a candidate Space Shuttle Payload specialist. In 2010, he became a suborbital payload specialist trainee, and is expected to fly several space missions aboard XCOR and Virgin Galactic vehicles in 2016-2017.

Before receiving his doctorate from the University of Colorado in 1989, Dr. Stern completed twin master's degrees in aerospace engineering and atmospheric sciences (1980 and 1981), and then spent six years as an aerospace systems engineer, concentrating on spacecraft and payload systems at the NASA Johnson Space Center, Martin Marietta Aerospace, and the Laboratory for Atmospheric and Space Physics at the University of Colorado. His two undergraduate degrees are in physics and astronomy from the University of Texas (1978 and 1980).

Dr. Stern has published over 230 technical papers and 40 popular articles. He has given over 300 technical talks and over 150 popular lectures and speeches about astronomy and the space program. He has written two books, *The U.S. Space Program After Challenger* (Franklin-Watts, 1987), and *Pluto and Charon: Ice Worlds on the Ragged Edge of the Solar System* (Wiley 1997, 2005). Additionally, he has served as editor on three technical volumes, and three collections of scientific popularizations: *Our Worlds* (Cambridge, 1998), *Our Universe* (Cambridge, 2000), and *Worlds Beyond* (Cambridge, 2003).

Dr. Stern has over 25 years of experience in space instrument development, with a strong concentration in ultraviolet technologies. He has been a Principal Investigator in NASA's UV sounding rocket program, and was the project scientist on a Shuttle-deployable SPARTAN astronomical satellite. He was the PI of the advanced, miniaturized HIPPS Pluto breadboard camera/IR spectrometer/UV spectrometer payload. Dr. Stern is also the PI of the Alice UV Spectrometer for the ESA/NASA Rosetta comet orbiter, launched in 2004, and served as the PI of the LAMP instrument on NASA's Lunar Reconnaissance Orbiter (LRO) mission, which launched in 2009.

Dr. Stern's academic research has focused on studies of our solar system's Kuiper Belt and Oort cloud, comets, the satellites of the outer planets, the Pluto system, and the search for evidence of solar systems around other stars. He has also worked on spacecraft rendezvous theory, terrestrial polar mesospheric clouds, galactic astrophysics, and studies of tenuous satellite atmospheres, including the atmosphere of the moon.

Dr. Stern is a fellow of the AAAS, the Royal Astronomical Society, and the IAF, and is a member of the AIAA, AAS, and the AGU; he was elected incoming chair of the Division of Planetary Sciences in 2006. He has been awarded the Von Braun Aerospace Achievement Award of the National Space Society, the 2007 University of Colorado George Norlin Distinguished Alumnus Award, the 2009 St. Mark's Preparatory School Distinguished Alumnus Award, and Smithsonian Magazine's 2015 American Ingenuity Award.

Dr. Stern's personal interests include running, hiking, camping, and writing. He is an instrument-rated commercial pilot and flight instructor, with both powered and sailplane ratings. He and his wife Carole have two daughters and a son; they make their home near Boulder, Colorado.

Chairman SMITH. Thank you, Dr. Stern, just fascinating.
Dr. Russell.

TESTIMONY OF DR. CHRISTOPHER RUSSELL, PRINCIPAL INVESTIGATOR, DAWN MISSION, AND PROFESSOR OF GEOPHYSICS AND PLANETARY PHYSICS, UNIVERSITY OF CALIFORNIA LOS ANGELES

Dr. RUSSELL. Thank you, Mr. Chairman, for providing me an opportunity to review Dawn's recent scientific discoveries, to explain their relevance, and to discuss future missions. I'd like to begin with a few words about Dawn itself. Dawn is the ninth mission in the NASA Discovery program. These missions are Principal-Investigator-led, they are relatively low cost, and are focused investigations selected by peer review from proposals submitted by planetary scientists.

May I have the first graphic, please?

[Slide.]

This shows the Dawn spacecraft, an artist's conception, at launch from Earth in 2007. Dawn has achieved several important firsts in space exploration. It's the only spacecraft ever to orbit two extraterrestrial bodies beyond the Earth, and only to orbit an object in the main asteroid belt between Mars and Jupiter.

Moreover, Dawn was the first scientific mission to use solar electric propulsion. Because electric propulsion thrusters accelerate the fuel over 10 times faster than chemical engines, smaller launch vehicles and smaller spacecraft can be used to do more exploration. This has enabled Dawn to visit the giant proto-planet Vesta, which was a fascinating world, closely related to the terrestrial planets, and more than typical asteroids—they're—it's more of a planet—and then to travel to Ceres to enter Ceres' gravitational field and to begin to map this dwarf planet.

By using the new technology of ion propulsion, we've accomplished more than we would have been—would have been possible with conventional technology and done so at 1/3 of the price.

Can I have the next graphics, please?

[Slide.]

This shows how we map. We go into a high-altitude circular orbit and then move in closer and closer getting higher resolution. And on the right-hand side is a color picture made by stretching the color images that we got from the camera.

We also—besides taking pictures, we measure in the visible and infrared spectra and look at gamma rays. We measure the gravitational field to get the mass distribution of the body and also look at the elemental composition.

In 2012 Dawn completed its measurements of Vesta, which is the second-largest body in the asteroid belt, and then we validated the model of the solar system evolution that had been developed for meteorite evidence by validating that the meteorite evidence had been correct.

We learned much about Vesta and we believe that Vesta was a precursor to the bodies that formed the Earth, that the bodies in the asteroid belt, many of them accumulated to form larger bodies.

The Earth's core may have first been formed in smaller bits in Vesta-like bodies.

Next graphic, please.

[Slide.]

This brings us to Ceres. We have a color map of the surface. This is stretched, but it shows the diversity of processes that must have been going on within Ceres. And on the right we have an elevation topography of a section of the surface and it's much more muted than Vesta was, as if—that we have a lot of erosion on the surface, much like Mars.

Then, we now are looking at Ceres from about 4,000 kilometers. We are now moving down to get higher resolution.

Next graphic, please.

[Slide.]

This shows two of the more famous landmarks. This—the first on the left-hand side is the Occator crater with bright spots. We believe these are salt left by evaporating water, as occurs in the Earth's deserts. This evaporation also makes a haze layer that we can occasionally see in the crater. We've got other features like—that look like pingos on the left—on the right-hand side. It's a small mountain about three miles high. It's got some dirt on it but it looks like it has ice coming down the sides. We are totally surprised by the Pluto observations that showed mountains on Pluto that were very much like this mountain that I show you here.

We have two more orbital phases for Ceres. We'll go down to as low as 200 miles above the surface, get gravity field measurements and the elemental composition, and then we will park the spacecraft in a stable orbit to protect it from crashing into the surface.

Ceres is an object with potential biological interest. It's got water and heat from the sun and the interior. The astrobiological community is very interested in Ceres. We've shown that Ceres is relatively easy to reach with a significant payload if you use ion propulsion. Ceres has a much lower gravitational field than Mars and the thrust needed to land is much less, so landing is very feasible.

Rover missions, landers such as the upcoming InSight mission to Mars, are all possible and highly desirable. We believe that Dawn, with its small exploratory payload, has only scratched the surface so to speak of what could be done.

I'd like to close with a brief but heartfelt thank you for you and your support of a strong space program. This support has brought a treasury of knowledge and a legacy for future generations. Thank you.

[The prepared statement of Dr. Russell follows:]

Hearing of the House Committee on Science, Space and Technology

"The Exploration of our Solar System: From Mercury to Pluto and Beyond"

Tuesday, July 28, 2015 – 10 AM Rayburn House Office Building

Testimony of Dr. Chris Russell

Dawn Principal Investigator

Professor of Earth, Planetary and Space Sciences

University of California, Los Angeles

Thank you, Mr. Chairman, for providing me an opportunity to review Dawn's recent scientific discoveries at the dwarf planet Ceres; to explain their relationship to an overall planetary program; and to discuss possible future missions of scientific interest in the asteroid belt. I begin by describing the Dawn mission itself since this mission is in many ways unique in our exploration program. Dawn is the ninth mission in NASA's Discovery Program. Discovery missions are Principal-Investigator-led, relatively low cost, focused-investigations that are selected by peer review from proposals submitted by planetary scientists. . The Dawn mission has achieved several important firsts in space exploration. It is the only spacecraft ever to orbit two extraterrestrial bodies beyond Earth, and the only to orbit an object in the main asteroid belt between Mars and Jupiter. Dawn is also the first scientific mission to use solar-electric ion propulsion. Figure 1 shows a Dawn ion thruster.

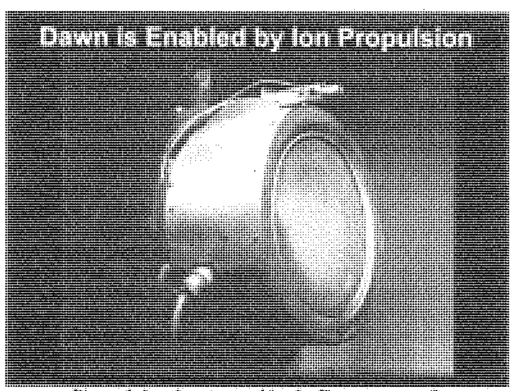


Figure 1. Ion thruster used by the Dawn spacecraft

Because electric ion thrusters accelerate their fuel more than 10 times faster than conventional chemical engines, smaller launch vehicles and smaller spacecraft can be used. This propulsion system enabled Dawn to first visit Vesta, the second most massive asteroid in the main belt, in 2011; orbit Vesta for a year; and then to leave Vesta and travel to the dwarf planet Ceres. Dawn entered orbit about Ceres in March 2015 and has been mapping it since April. Use of the new technology of ion propulsion enabled us to accomplish more than we could with conventional technology. And it is important to note that we did so at one third the price that conventional technology would have required. Dawn has accomplished what no other mission has accomplished. Other missions have flown by more than one planet but Dawn is the first and only mission to *orbit* two distant planetary bodies.

Dawn at Vesta:

Dawn conducts its investigations by orbiting its target from pole to pole in a set of circular orbits that map the body at different resolutions. It measures the gravitational attraction and thus the mass of the body and the distribution of mass using its radio system. It images in visible wavelengths and in the infrared wavelengths. It maps gamma rays and neutrons. Vesta is the second most massive body in the asteroid belt between Mars and Jupiter. The stretched-color image of Vesta (Figure 2) illustrates the internal diversity of Vesta as reflected in its surface. It is not simply a block of a single type of rock, but it has evolved geochemically to form new minerals after accretion.

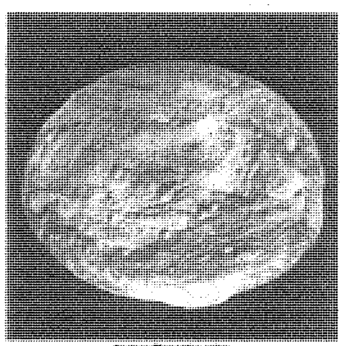


Figure 2. Vesta as seen in color ratios derived from the Dawn camera color filters

The measurements that Dawn completed at Vesta in 2012 were very important in testing our understanding of the origin and evolution of the solar system. Many meteorites from Vesta have

fallen on the Earth. These meteorites have been geochemically analyzed and interpreted, which has enabled us to develop a model of the formation and evolution of Vesta.. Had our understanding been incorrect, we would have predicted the wrong structure for Vesta. However, we found our model was quite accurate and the standard model of solar system formation was secure. Furthermore, we learned much about the structure and interior of Vesta, a body similar to those we believe came together to build the Earth. Thus we learned a little about our planet as well.

Dawn at Ceres:

In September 2012, Dawn left Vesta and headed farther out in the solar system to rendezvous with Ceres, arriving in March of 2015. While Vesta had given scientists on Earth much evidence of how it was formed, Ceres had provided Earth with no evidence that we could recognize or understand. The surface is dark and the topography is muted compared to other asteroids. We expected to see signs of water but could not see any from Earth since water in the Earth's atmosphere hides any Ceres water. Hubble data could not resolve the water mystery either. More recently, the European Herschel Space Observatory reported intermittent signs of water in the very weak atmosphere of Ceres. Further, radar measurements from Earth find the surface to be clay-like, suggestive of the presence of water at some time in the past.

Our initial images of the surface of Ceres reveal a very dry surface, but with bright spots on the surface. We think the bright regions are salt deposits where water has reached the surface and evaporated. As shown in Figure 3, the surface is diverse due to active geochemical and dynamic processes inside. This picture again uses color ratios. Our current thinking is that the surface of Ceres is like permafrost. There is water in the soil but it is frozen. Water is only released during meteor impacts and perhaps other tectonic events. We have some pictures that suggest occasional haze clouds and some scattering of light above the dark limb. So there definitely is a very thin atmosphere on Ceres. At some depth below the surface there should be liquid water.

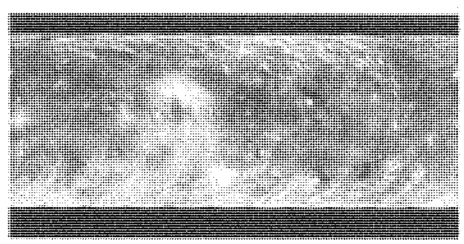


Figure 3. Color ratio image of Ceres illustrating the diversity of processes originating inside Ceres

In many ways Ceres resembles the planet Mars. It is colder than Mars. It does not have as much iron as Mars, as you would expect from the difference in color (Mars is a rusty red; Ceres is dark gray). Both have structures on the surface where it appears that ice once stood and later evaporated. A difference is that on Mars there is exposed ice. We have yet to find exposed ice on Ceres. Figure 4 shows a color-coded elevation map of a large crater on Ceres. The surface appears to be smooth and eroded.

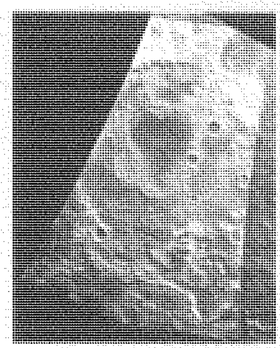


Figure 4. Color-code elevation map showing a portion of the surface of Ceres. Surface has been smoothed by geologic processes giving an appearance similar to that of Mars

Perhaps the freshest and most noticeable surface feature on Ceres is the cluster of bright spots in the Occator crater shown in Figure 5. We currently believe the bright material is salt brought to the surface by water or water vapor.

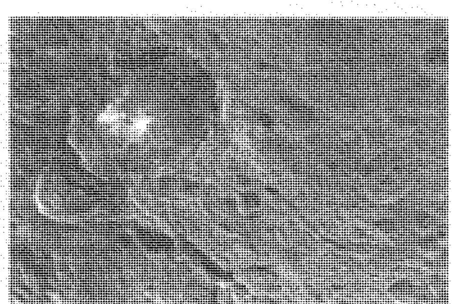


Figure 5. View of Occator crater where brightest spots on Ceres are located

We also have surface features that may be like terrestrial pingos, small mountains covered in dirt with ice inside. These can be found on Earth in Alaska where there is permafrost. There is one large mountain (shown in Figure 6) that is 3 miles high and because of its shape and uniqueness has been dubbed the pyramid. Speculation is that it is like a giant pingo but no one has yet provided good evidence for that theory. Ice pressure could be strong enough to raise such a mountain on a small planet like Ceres. The New Horizons mission detected similar mountains on Pluto.

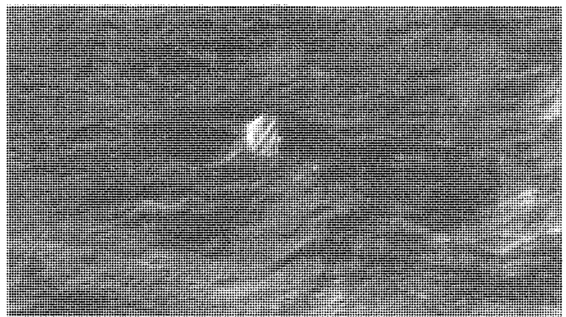


Figure 6. The so called pyramid on Ceres, a 3 mile high mountain whose origin is not yet understood

Our Continued Exploration of Ceres:

Dawn was designed for a finite lifetime and is reaching the end of its onboard supply of propellants. Thus, it is expected to terminate its exploration program in early 2016. There are two stages of exploration remaining. In September 2015, we will begin our high altitude mapping orbit. This phase of the mission gives us our best model of the surface elevations using stereo photography. We will get more color photography of the surface and spectral information that will help identify the minerals present on the surface.

In the new year, we will move the spacecraft even closer to the surface to the low altitude mapping orbit, where our resolution of the surface is highest. We will also obtain gamma ray and neutron data that can identify the elemental composition of the surface and learn more about the presence of water and ice near the surface. We will also obtain our best information about the gravity field of the planet at this time.

The end of the mission will come when we run out of propellant to point the spacecraft. We need to turn the spacecraft to point at the surface in order to obtain camera and spectrometer data, and we need to point the telemetry antenna to Earth to return the data from the spacecraft. We need to point the thrusters in yet another direction to move closer to or further from Ceres.

When Dawn's propellant is exhausted, the spacecraft will simply remain in a safe orbit for at least 50 years, the time required by planetary protection.

Potential Biological Interest:

Ceres is an object of interest to the biological community. Ceres has water and heat sources from the Sun and from its interior. It might sustain life. Ceres is relatively easy to reach from Earth but does take longer to reach than the Moon or Mars. However, being less massive than the Moon or Mars, landing on the surface should be easier at Ceres. While aerobraking and parachutes are helpful at Mars, they cannot be used at Ceres since Ceres has no substantial atmosphere, much like the Moon. However, retro rockets like used on the Moon and on Mars would work well in Ceres' very weak gravity field.

Future Exploration of Ceres:

The arrival of Dawn at Ceres has raised much interest in further exploration. Dawn has a very elementary payload. There is much more that could be done from orbit and much to be gained from landing on the surface of Ceres. Surface landers could return much information about the nature of the surface and the interior of Ceres. A rover, even a very simple one, would teach us much about Ceres. The biological potential of Ceres can only be best assessed only from the surface. Thus there is much interest on landing on this body.

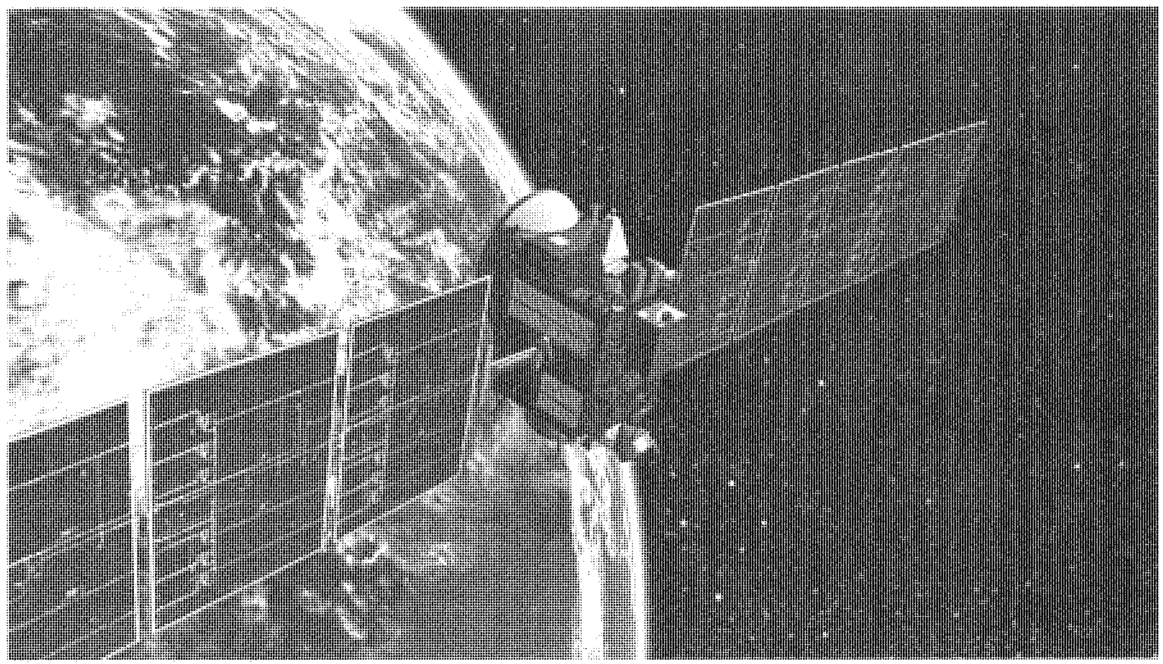
Closing Comments:

I would like to close this testimony with a short thank you. I have been fortunate enough to participate in space exploration of the Earth, the Sun and the planets during the past half century since I graduated from college. Of course this has been exciting to me personally, but it also has provided a treasury of knowledge about the solar system and a legacy for future generations. I appreciate this opportunity to thank you personally.

Graphics
C. T. Russell

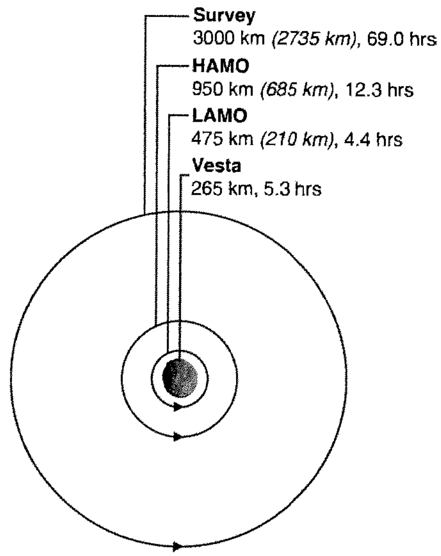
P.I. Dawn Mission to Vesta and Ceres

The Dawn Mission

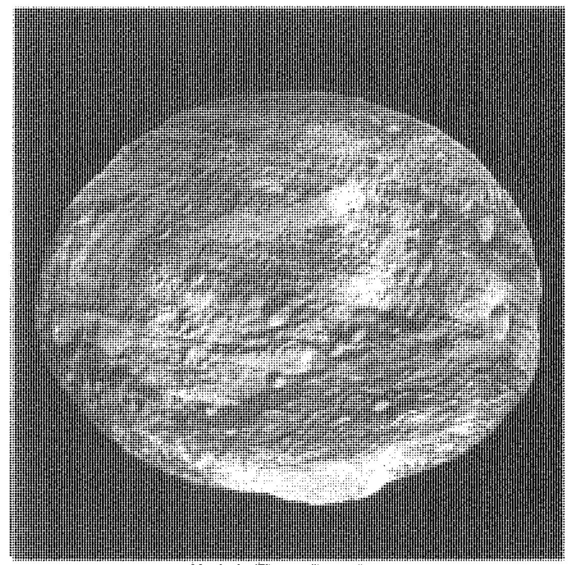


Dawn spacecraft leaving Earth on Sept.27, 2007

Mapping at Vesta



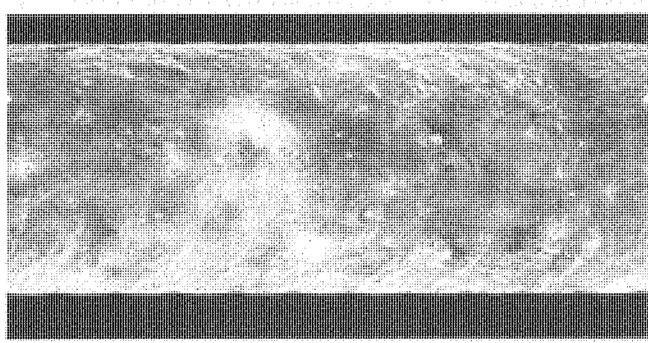
Mapping orbits used to study Vesta, July 2011 – Sept.2012



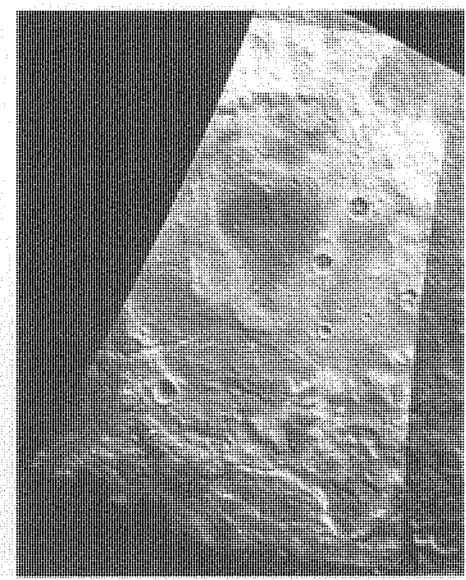
Vesta in Clementine colors

Vesta as seen in color ratios derived from Dawn color filters

Mapping the Surface of Ceres

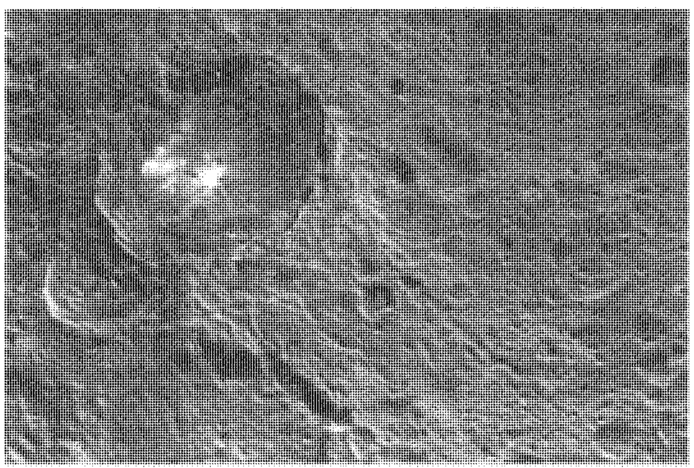


Color ratio image of Ceres illustrating
the diversity of materials on Ceres

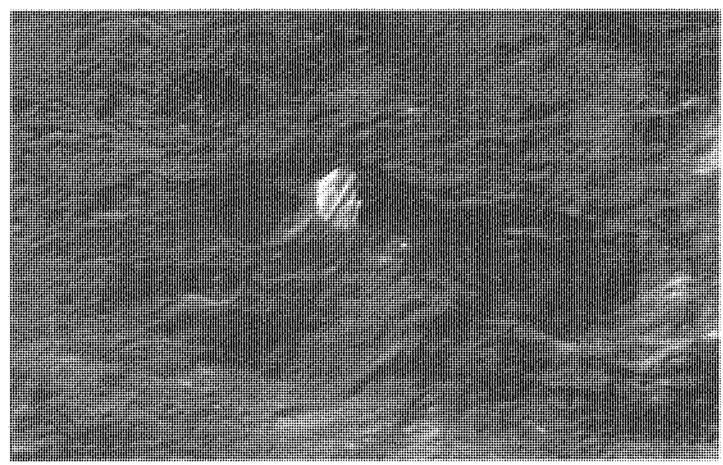


Color contour model of part of
surface of Ceres

Surface Features on Ceres



Occator Crater with bright spots



Three mile high mountain on Ceres

Brief Biography – Prof. C. T. Russell

Dr. C. T. Russell is a Professor of Earth, Planetary and Space Sciences at the University of California, Los Angeles. He received his Ph. D. from UCLA in 1968. He is a Fellow of the American Geophysical Union and the American Association for Advancement of Science. He has received the AGU's Macelwane and Fleming Medals and COSPAR's Science Award. He has published over 1500 scientific papers that have received over 44,000 citations and he has an H-index of 97. As a graduate student he worked on the OGO-1 through 6 missions from 1965-1968. After graduating, he worked on the Apollo 15 and 16 subsatellites; led the magnetic investigation on the International Sun-Earth Explorers 1 and 2; on the Pioneer Venus Orbiter and the International Solar Terrestrial Probe, Polar mission. He has also participated in the Galileo, Cassini, Near Earth Asteroid Rendezvous, STEREO, and THEMIS missions. Currently he is the principal investigator of the Dawn mission, the principal investigator of the magnetic fields investigation on the Magnetospheric Multiscale mission and the lead investigator for the magnetometer for the InSight Mars lander.

Chairman SMITH. Thank you, Dr. Russell.
And, Dr. Pappalardo.

TESTIMONY OF DR. ROBERT PAPPALARDO, STUDY SCIENTIST, EUROPA MISSION CONCEPT, JET PROPULSION LABORATORY, NASA

Dr. PAPPALARDO. Chairman Smith, Ranking Member Edwards, and other Members of the Committee, I'm very happy to appear before you to discuss NASA's Europa project. I note that I do so as an employee of the Jet Propulsion Laboratory, which is a federally funded research and development center managed by the California Institute of Technology for NASA.

Jupiter's moon Europa is one of the most likely places to find current life beyond our Earth. For over 15 years, NASA has studied a variety of mission concepts to explore Europa and determine if it could be habitable. My own fascination with ice-covered moons of the outer solar system blossomed in 1985, with a seminar course at Cornell University taught by Carl Sagan entitled "Ices and Oceans in the Outer Solar System." Though I was just an undergraduate, Sagan allowed me to audit this graduate course. In some sparkling moments, Sagan was as brilliant a teacher as one could imagine and inspired what would become my career.

I joined my first Europa mission Science Definition Team back in 1998. Now, working at NASA's Jet Propulsion Laboratory, I'm the Project Scientist for the burgeoning Europa mission, serving as the interface between the engineering team and the recently selected science team.

In the late 1990s, NASA's Galileo mission to Jupiter produced strong evidence that Europa, which is about the size of Earth's moon, has a global ocean beneath its frozen crust. This ocean could contain more than twice as much water as Earth. With abundant saltwater, a rocky seafloor, and chemical energy that could potentially be transported to the ocean by processes powered by tidal heating, Europa might have the ingredients necessary to support simple organisms.

Europa's rich and diverse geology and its probable subsurface liquid water ocean are both believed consequences of the strong tides that heat the interior and flex the surface to its breaking point. Europa's chaotic terrains, which are regions of disrupted surface ice, display similarities to features in Antarctica, suggesting that they could be surface manifestations of shallow subsurface lakes. If that's true, these lakes are possible abodes for life at Europa. Europa's chaotic regions are commonly brownish-red in color with infrared signatures that are suggestive of salts, probably derived from the ocean below.

NASA's Europa mission plan calls for a spacecraft to be launched to Jupiter in the 2020s, arriving at the distant planet after a journey of several years. The current plan envisions a spacecraft that would have an expected lifetime of more than three years and would orbit the giant planet about every two weeks, providing many opportunities for close flybys of Europa. During these flybys, the spacecraft would achieve near global coverage, image the

moon's icy surface at high resolution, and investigate its composition and the structure of its ocean and icy shell.

NASA announced the instruments for the Europa mission's scientific payload on May 26. The payload of nine selected science instruments includes cameras and spectrometers that will produce high-resolution images of Europa's surface and determine its detailed composition. An ice-penetrating radar can determine the thickness of the moon's icy shell and search for subsurface lakes, similar to those beneath Antarctica.

The mission also will carry a magnetometer to measure the strength and direction of the moon's magnetic field to allow scientists to probe the thickness and saltiness of its ocean. A thermal instrument will scour Europa's frozen surface in search of recent eruptions of water or warm ice, while additional instruments will sample tiny particles of water, dust, and plasma in the moon's extremely thin atmosphere.

NASA's Hubble Space Telescope observed water vapor above the south polar region of Europa in 2012, providing tantalizing evidence of water plumes. If plumes are confirmed, and if they can be linked to the subsurface ocean, they'll allow us to interrogate the chemical makeup of Europa's potentially habitable subsurface environment, while minimizing the need to drill into the ice.

Just last month, NASA completed its first major review of the Europa flyby mission, which has now entered the development phase known as formulation. During the remainder of 2015 and through fiscal year 2016, the project will work to develop science requirements, mission architecture, planetary protection requirements, risk identification and mitigation plans, cost and schedule estimates, as well as payload accommodation for the instruments for the mission to Europa.

In short, NASA is formulating a project that could lead to fundamental discoveries about Europa. This is will be both an ambitious and an exciting undertaking. Just as with that graduate Carl Sagan course I took at Cornell, this mission will be at the cutting edge of science and engineering and is sure to inspire the next generation.

Thank you, and I look forward to any questions.

[The prepared statement of Dr. Pappalardo follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
July 28, 2015

Statement of

Dr. Robert Pappalardo
Europa Mission Project Scientist
Jet Propulsion Laboratory
National Aeronautics and Space Administration

before the
Committee on Science, Space and Technology
U.S. House of Representatives

Chairman Smith, Ranking Member Johnson, and other Members of the Committee, I am very happy to appear before you to discuss NASA's Europa project.

Jupiter's moon Europa is one of the most likely places to find current life beyond our Earth. For over 15 years, NASA has studied a variety of mission concepts to explore Europa and determine if it could be habitable. Key scientific interests include the characteristics of Europa's vast ocean, the interface between the ice and the ocean, the chemical composition of its intriguing brownish surface areas, and the current geological activity that provides energy to the system.

My own fascination with the ice-covered moons of the outer solar system blossomed in 1985, with a seminar course at Cornell University taught by Carl Sagan entitled "Ices and Oceans in the Outer Solar System." Though I was just an undergraduate, Sagan allowed me to audit this graduate course. In some sparkling moments, Sagan was as brilliant a teacher as one could imagine, and inspired what would become my career.

I joined my first Europa mission Science Definition Team in 1998. Now, working at NASA's Jet Propulsion Laboratory, I am the Project Scientist for the burgeoning Europa mission, serving as the interface between the engineering team and the recently selected science team.

Europa Science

In the late 1990s, NASA's Galileo mission to Jupiter produced strong evidence that Europa--about the size of Earth's moon--has a global ocean beneath its frozen crust. This ocean could contain more than twice as much water as Earth. With abundant salt water, a rocky sea floor, and the chemical energy that could potentially be transported to the

ocean by processes powered by tidal heating, Europa might have the ingredients needed to support simple organisms.

Europa's tidal heating stems from interplay with its neighboring moons Io and Ganymede. What this means is that every time Europa completes one orbit of Jupiter, it aligns with Io, and every second orbit, it aligns with Ganymede. Gravitational interactions among these moons keep their orbits slightly elliptical. So throughout each Europa orbit, the distance to Jupiter changes, raising tidal bulges that constantly modify Europa's global shape. Europa's rich and diverse geology, and its probable subsurface liquid water ocean, are both believed consequences of the strong tides that heat the interior and flex the surface to its breaking point.

Europa's chaotic terrains—regions of disrupted surface ice—display similarities to features in Antarctica, suggesting that they could be surface manifestations of shallow subsurface lakes. If that is true, these lakes are possible abodes for life at Europa. Europa's chaotic regions are commonly brownish-red in color, with infrared signatures that are suggestive of salts, probably derived from the ocean below.

NASA's Europa Mission

NASA's Europa mission plan calls for a spacecraft to be launched to Jupiter in the 2020s, arriving at the distant planet after a journey of several years. The current plan envisions a spacecraft that would have an expected lifetime of more than three years and would orbit the giant planet on average about every two weeks, providing many opportunities for close flybys of Europa. Building on technologies and techniques developed for the Cassini and Juno missions, the current mission plan includes 45 flybys, at altitudes varying from 1,700 to just 16 miles above the surface. During these flybys, the spacecraft would achieve near global coverage, image the moon's icy surface at high resolution, and investigate its composition and the structure of its ocean and icy shell.

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In short, NASA is formulating a project that could lead to fundamental discoveries about Europa. This is will be both an ambitious and an exciting undertaking. Just as with that graduate Carl Sagan course that I took at Cornell, this mission will be at the cutting-edge of science and engineering, and is sure to inspire the next generation.

Thank you, and I look forward to any questions you might have.

Robert Pappalardo
Europa Mission Project Scientist

Robert Pappalardo is a Senior Research Scientist in the Planetary Science Section, Science Division.

Pappalardo's research focuses on processes that have shaped the icy satellites of the outer solar system, especially Europa and the role of its probable subsurface ocean. Europa research includes the possibility that solid-state convection has played an important role in the satellite's history, investigation of regions of separation and spreading of the satellite's icy lithosphere, and implications of the surface geology for lithospheric properties and the existence of a liquid water ocean beneath the icy surface. Additional recent research involves the nature, origin, and evolution of bright grooved terrain on Jupiter's moon Ganymede, specifically the style of tectonism and implications for the satellite's geological history. Also, he is investigating the geological implications of geyser-like activity on Saturn's moon Enceladus and of processes that shape the surface of Satum's moon Titan.

In 1986 he received his B.A. in Geological Sciences from Cornell University, and in 1994 he obtained his Ph.D. in Geology from Arizona State University. As an affiliate member of the Galileo Imaging Team while a researcher at Brown University, he worked to plan many of the Galileo observations of Jupiter's icy Galilean satellites. From 2001-2006, he was an Assistant Professor of Planetary Sciences in the Astrophysical and Planetary Sciences Department of the University of Colorado at Boulder, and he continues to mentor graduate student researchers. Along the way, he has worked with various science museums and organizations to bring the excitement of astronomy and planetary exploration to the public.

Chairman SMITH. Thank you, Dr. Pappalardo.
And, Dr. Braun.

TESTIMONY OF DR. ROBERT BRAUN, DAVID AND ANDREW LEWIS PROFESSOR OF SPACE TECHNOLOGY, GEORGIA INSTITUTE OF TECHNOLOGY

Dr. BRAUN. Mr. Chairman, Ranking Member Edwards, and members of the Committee, thank you for the invitation to share my views of the exciting future of America's solar system exploration program here today. I'm the engineer at the table, and I must say it's an honor to be seated here with some of the world's planetary science luminaries.

I've been a faculty member at the Georgia Institute of Technology since 2003, and judging by the passion and creativity of the students that I see every day on campus, I'm confident that the grandest era of space exploration lies ahead of us.

I presently serve as Vice Chair of the National Research Council's Space Studies Board and Chair of NASA's Standing Review Board for the 2020 Mars Project. However, I'm here today as an individual and the views I express are mine alone.

Planetary science is one of America's crown jewels. These endeavors have consistently reminded people worldwide that the United States was not just founded as a bold and curious nation but continues to lead in discovering and exploring the richness of the worlds beyond our own for the betterment of all.

Beginning more than 50 years ago with the Mariner 2 mission to Venus, the United States has consistently led the exploration of our solar system. Decade by decade we have designed, built, and operated a balanced portfolio of missions targeting destinations across the solar system. Today, as we celebrate successes like New Horizons' visit to Pluto and Dawn's mission to Vesta and Ceres, another U.S. spacecraft is on its way to Jupiter, two U.S. rovers trundle across the Mars surface, and U.S. orbiters at Mars and Saturn are returning tantalizing insights. And yet there are still so many questions to answer.

We now know of a multitude of ocean worlds in our own cosmic backyard. This list obviously includes the Earth but also Jupiter's moons Europa, Ganymede, and Callisto; Saturn's moons Enceladus and Titan; and Neptune's moon Triton. Enceladus and Europa maybe the two worlds in our solar system best suited to search for life as we know it, whereas Titan is likely the best place to search for life as we don't know it.

Accessing the water within these ocean worlds should be one of our next great planetary science quests, one with ramifications for understanding the emergence of life on Earth and the potential for life elsewhere. That's why it's surprising today, even considering the work being done towards the mission to Europa, that there are no planned missions in NASA's planetary science portfolio to access the water in locales where we know it to exist.

Because the transit times, distances, and radiation and surface environments of these ocean worlds differ so significantly from vistas we have previously been, new engineering capabilities and tech-

nologies must be developed, particularly if we want to land, rove, or dive within the ocean worlds.

Fortunately, many of the needed technologies, including advanced power systems, radiation protection, sensing, landing, navigation, and communication technologies were included in the 2015 House Appropriations bill for NASA. Through these investments, the number and capability of missions to the outer planets is poised for growth.

NASA has a successful track record in development of game-changing technologies to enable planetary science. Were it not for the successful technology demonstration of solar electric propulsion by the Deep Space 1 mission in the late 1990s, Dawn would not likely have been selected as a discovery mission. This technology has since been commercialized to the benefit of the U.S. satellite industry.

As a result of NASA's high-efficiency solar cell technology investments, the Juno mission is now en route to Jupiter. It's the first solar-powered spacecraft to travel beyond Mars, a region where nuclear power had previously been required. This technology is now making its way onto other science missions, including the Europa mission, and is affecting our solar power infrastructure here at the Earth.

These examples demonstrate that development efforts, external to flight programs can be effectively used to retire new technology, risk, and cost. In fact, removing technology development risk from its flight programs has been cited numerous times by the Government Accountability Office as a means to better manage NASA's spaceflight missions.

Humanity should be proud. We've now completed a first investigation of each major celestial body in our own solar system. Now is the time to accelerate the pace and the scope of our nation's solar system exploration program. Let's sample the water of our solar system's ocean worlds. To do so, we must couple our scientific drive with investments in the critical space technologies required to accomplish these goals. Underscoring our country's scientific prowess, engineering creativity, and technological skill, this is a journey sure to inspire the world.

Thank you again for the opportunity to be here today. I look forward to your questions.

[The prepared statement of Dr. Braun follows:]

Statement of
Dr. Robert D. Braun
Georgia Institute of Technology
to the
Committee on Science, Space and Technology
United States House of Representatives
on
Exploration of the Solar System: From Mercury to Pluto and Beyond
July 28, 2015

Mr. Chairman, Ranking Member Johnson and members of the Committee, thank you for the invitation to appear before you today to share my view of the exciting future of our nation's solar system exploration program. It is an honor to be seated at this table with some of our world's planetary science heroes. My name is Robert D. Braun. I'm an engineer and a technologist. The views I express today have been shaped through a 28-year aerospace engineering career in government, industry and academia. I started my career as a member of the technical staff of the NASA Langley Research Center. As a young engineer at Langley, I was given the freedom to dream big. I developed advanced space exploration concepts, led multiple technology development efforts, and contributed to the design, development, test and operation of several robotic Mars spaceflight systems beginning with the Mars Pathfinder mission, which included the first rover to visit the Red Planet.

Since 2003, I have been fortunate to serve on the faculty of the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology. At Georgia Tech, I lead a research and educational program focused on the design of advanced technologies and mission concepts for planetary exploration. Judging by the passion and creativity of the students I see everyday on the campus of Georgia Tech, this nation's grandest era of space exploration is ahead of us. It gives me great pride to work closely with these students, who are on their way to creating economic, national security and societal value for our nation through our space program.

In 2010-2011, I was honored to serve as NASA's first Chief Technologist in more than a decade, creating and leading the development of a spectrum of broadly applicable technology programs designed to build the capabilities required for our nation's future space missions. I presently serve as Vice Chair of the National Research Council's Space Studies Board and Chair of the Standing Review Board Chair for the Mars 2020 Project. However, I am here today as an individual and the views I express are mine alone.

Continuing U.S. Leadership in Solar System Exploration

Planetary science is one of America's crown jewels. A unique symbol of our country's technological leadership and pioneering spirit, this endeavor has consistently demonstrated that the United States is a bold and curious nation interested in discovering and exploring the richness of worlds beyond our own for the betterment of all. In addition to informing our worldview, these missions are inspirational beacons, pulling young people into educational and career paths aligned with science, technology, engineering and mathematics, the foundation of continued U.S.

economic competitiveness and global leadership in a world that is becoming more technologically advanced with each passing year.

We are not alone in this enterprise. The emergence of the Chinese and Indian space programs and the continued successes of the European and Japanese programs illustrate that, much like human exploration, robotic exploration of space is an international priority – a way to gain scientific knowledge, global prestige and advance technological capability. In the coming decade, China is preparing a series of robotic lunar missions, Russia is preparing lunar, Venus and Mars missions, India is planning to follow-up on its successful Moon and Mars experiences, Japan is planning a second asteroid sample return mission, the United Arab Emirates is planning a Mars mission, and following up on the flight of the Rosetta spacecraft and Philae lander, the Europeans are headed to Mercury, Mars, and Jupiter. Clearly, other nations believe that solar system exploration is a worthwhile endeavor and a credible measure of scientific innovation, engineering creativity, and technological skill.

Beginning with the flight of Mariner 2 more than 50 years ago, the United States has consistently led the robotic exploration of our solar system. Decade-by-decade, we have created and operated a balanced portfolio of missions to explore destinations across the solar system. In just the past decade, we have proven that large quantities of water once flowed across the Mars surface, that vast hydrocarbon seas exist on the surface of Titan, and that there is a diverse set of ocean worlds in our own solar system waiting to be explored. Today, as we celebrate the success of the New Horizons mission to Pluto and the Dawn mission to Vesta and Ceres, another U.S. spacecraft is enroute to Jupiter, two U.S. rovers trundle across the Martian surface, and U.S. orbiters at Mars and Saturn are returning tantalizing insights. We have learned that our solar system and other planetary systems are exceedingly diverse. From the dusty plains of Mars to the subsurface ocean of Jupiter's moon Europa to the hydrocarbon seas on Saturn's moon Titan to the thick carbon dioxide greenhouse of Venus, there remains much to discover in our cosmic backyard.

Moving beyond the investigations carried out by our initial robotic emissaries, there is no shortage today of scientifically compelling mission concepts, designed to answer fundamental questions about who we are, where we may have come from, where we are going and—perhaps the most fundamental of them all—are we're alone? Potential planetary science missions of the next decade include returning scientifically selected samples from Mars, accessing the Mars subsurface, analyzing and returning samples from the nucleus of a comet, sampling the liquid water of one or more ocean worlds, surveying the geology of the Venus surface, sailing the hydrocarbon seas of Titan, exploring the mysterious ice giants Uranus and Neptune that stand like sentinels at the solar system's edge, and perhaps, one day, taking flight on an interstellar journey to another Earth. There is no shortage of exciting vistas remaining for us to explore. These missions require technology development to improve or enable scientific return, reduce cost, or improve the pace of our journey. Using past NASA technology development experiences as a guide, I will discuss these technological advances in my testimony today.

Ocean Worlds

As our exploration journey expands, a compelling scientific theme focused on the diversity and distribution of liquid resources across the solar system is beginning to emerge. On Earth, where there is liquid water, there is life. As such, investigation of our solar system's ocean worlds has

potentially profound ramifications for understanding the emergence of life on Earth as well as the potential for life elsewhere in our solar system and across the universe. In addition to Earth, our present list of ocean worlds includes Jupiter's moons Europa, Ganymede and Callisto, Saturn's moons Enceladus and Titan, and Neptune's moon Triton. Enceladus and Europa may be the two worlds in our solar system best suited to search for life as we know it; Titan is likely the best place to search for life as we don't know it.

In my view, accessing water, in destinations where we know it exists, is the next great planetary science quest; one that may provide the answers to our fundamental questions regarding the potential for life across our solar system and the universe. To address these questions, we need to return to the outer planets with regularity and consistency of purpose. We need to work together to ensure future missions access the water at destinations in which we know it to exist. It is worth noting that today, even considering the work being done towards a mission to Europa, there are no planned missions in NASA's planetary science portfolio that would accomplish this.

Now is the time to organize and initiate a series of robotic missions focused on the fundamental questions of evolution, habitability and life across our solar system's ocean worlds. It is worth remembering that prior to flight of the Mars Pathfinder and Mars Global Surveyor missions in 1997, our nation went 20 years without the Mars Exploration Program that is today a central part of our U.S. space exploration identity. Spurred by the technology advances of these two missions (e.g., direct entry and aerobraking, among others), NASA changed the game at Mars, successfully implementing these projects for approximately one quarter the price of past missions. The technologies and approaches utilized fueled the creation of the Mars Exploration Program and its associated budget line, allowing for an increase in mission cadence that has enabled our advancement of Mars scientific knowledge over the past two decades.

In a similar vein, direct access to our solar system's oceans is now both technically and fiscally viable. Recall that it has not been any one mission or science measurement that has singularly changed our view of Mars. Rather, it has been the synthesis of evidence, gathered through an integrated set of measurements, obtained by a carefully engineered sequence of missions. Advancing Mars science required a prioritization of investigations, opportunities for relatively frequent launch, and a building-block approach in which technology advancement was made across a series of interconnected missions to improve science return over time. Built upon these same principles and the scientific foundation obtained from past missions, exploration of our solar system's ocean worlds is possible today as a result of critical technology investments and new capabilities that may bring the outer planets within reach of a broad set of missions.

At present, NASA is formally initiating the Europa Mission in accordance with the objectives of the planetary science decadal survey. However, going all the way to Europa without touching its surface is like driving across the country to Disneyland and then staying in the parking lot.

Viewed through a program lens, the addition of a small, astrobiology-focused lander to directly access the surface of this ocean world should be considered for potential launch with the Europa Clipper. A science-focused technology demonstration that proves our ability to safely and precisely access the fundamentally different surface environment of these ocean worlds should be the primary objective of this first U.S. outer planets lander. Providing unique imagery and

chemical analysis of the icy moon terrain, such a mission would be a pathfinder for a suite of future surface and subsurface astrobiology missions to access the water in these ocean worlds. Compiled as a sequence of interconnected missions, this is a journey sure to inspire the world and maintain U.S. leadership in space exploration.

Enabling Solar System Exploration

Numerous engineering and technical challenges need to be addressed to advance U.S. scientific exploration of the solar system. Because the transit times, distances, radiation environment and surface environments of these worlds differ so significantly from vistas we have previously visited and understand, new engineering capabilities and technical expertise must be developed, particularly to land, rove or dive at one of these destinations. If planned and managed appropriately, broadly applicable technology investments can be utilized to bring the exploration of these worlds within our reach.

Technology advancements being pursued today can greatly reduce the cost and increase the capabilities of future spaceflight systems for the exploration of a broad range of destinations, including the outer planets, their ocean worlds, Venus and Mars. Fortunately, many of the needed technologies, including advanced power systems (both solar and nuclear), radiation protection, sensing, landing, navigation and communications were identified for funding in the FY15 House Appropriations bill. These technology development activities have the potential to bring a broad range of compelling new missions into the realm of possibility, including Discovery, New Frontiers and Flagship class missions to outer planet destinations. Coupled, with the fielding of a heavy lift launch capability, presently in development by NASA and U.S. industry, an increased cadence and widening aperture of outer planet missions is possible in the decade of the 2020s.

NASA has a successful track record in the development of game-changing technologies and mission implementation approaches to enable planetary science. Consider the following short list of illustrative examples that span propulsion, power and atmospheric entry technologies:

Solar Electric Propulsion (SEP): In 1994, NASA initiated the New Millennium Program to develop and demonstrate technologies for future space science and exploration missions. The New Millennium Program flew its first deep space mission, Deep Space 1 or DS-1, in 1998. DS-1 included flight qualification of a dozen new space technologies, most of which have subsequently found their way into current NASA missions. However, the true superstar technology on DS-1 was the NSTAR solar electric powered ion propulsion system. DS-1 not only successfully demonstrated this revolutionary SEP system, but showed through its primary and extended missions the ability of SEP missions to encounter multiple comets (Braille and Borrelly), a technical feat not possible with traditional chemical propulsion systems. As a direct result of the flexibility of the SEP system (and unlike any previous planetary science mission), the DS-1 mission plan allowed for the selection of which comets to visit and for what timeframes during the performance of the actual mission.

With the DS-1 mission completed, this technology was ready for mission infusion. The demonstrated SEP efficiency, reliability and mission flexibility carried over directly into the

competitively selected Dawn mission. Launched in 2007, Dawn is powered by a DS-1 class SEP system operating at 10 kW, and like DS-1, has for various reasons needed to adjust it mission trajectory on the fly. Today, after nearly eight years of operations, and with the first scientific data set of Ceres continuing to be returned to scientists and the public here on Earth, it is clear that SEP technology has revolutionized the art of the possible in terms of space science and exploration. These advances in solar electric propulsion technology are useful beyond the scientific domain. Ion thruster technology has been transferred from these missions to the commercial satellite industry, and today most of our new geostationary communications satellites use ion thrusters to meet their orbital propulsion needs.

Solar Power: Following decades of investment in solar-cell technology by both government and industry, NASA conceived, designed and is now operating the first solar-powered robotic mission to Jupiter (Juno). In this case, solar power is used to operate the spacecraft as opposed to power its propulsion system. This distant location from the Sun is a regime where only nuclear-powered spacecraft were once thought possible. This breakthrough is enabling collection of planetary science through a New Frontiers mission at a cost not possible through alternative means. This same high-efficiency solar cell technology is now making its way into other space science missions, including the Europa Mission as well as the solar power infrastructure that supports our society here on Earth.

In the past few years, the Space Technology Mission Directorate has demonstrated innovative solar array structures whose mass has been cut in half and packaging volume reduced by two thirds. To further promote science mission infusion potential, NASA has offered this technology as Government Furnished Equipment in the most recent SMD Discovery solicitation. Coupling the efficiency improvements of the solar cells themselves with these gossamer solar array structure improvements, NASA investments in this technology appears poised to benefit the U.S. commercial telecommunications industry. SSL, Lockheed Martin, Boeing and ATK have held discussions with NASA regarding future utilization of these solar power systems, improving the performance and affordability, while reducing the mass, of future communications satellites.

PICA Heatshield: Following a decade of investment in lightweight carbon ablators, NASA matured the high-performance thermal protection system PICA that has enabled analysis of dust samples obtained from a comet following safe completion of the highest speed Earth reentry of all time (Stardust). Demonstrating the broad applicability of this technology, PICA was utilized to enable entry of the Mars Science Laboratory (MSL) after a potentially catastrophic problem was uncovered late in the development cycle of the initially-planned thermal protection system material. NASA's technology development efforts provided the mature PICA solution at precisely the needed instant in time, allowing the mission to move forward successfully. Without the prior development and availability of PICA, the Curiosity landing may never have occurred. Since that time, the SpaceX Dragon capsule has adopted a form of PICA as its heatshield material, while the Orion project also considered this material for potential use.

These examples of technology infusion share a common characteristic - each was matured from broadly applicable space technology roots, not mission-focused objectives. For example, when the time came for flight project development, Stardust and Mars Science Laboratory did not need to be planned inclusive of the cost and risk associated with the maturation of the PICA heatshield

material. Rather, technology development efforts external to these flight programs had already retired these risks and handled these costs. Similarly, Juno did not need to be planned inclusive of the cost and risk associated with the maturation of high-efficiency solar cells. DS-1 was not planned as a technology precursor to Dawn; however, its success certainly enabled Dawn's competitive selection as a Discovery mission. Removing this technology development risk has been cited numerous times by the GAO as a means to better manage NASA's future spaceflight missions. This is the principle upon which NASA's Space Technology Mission Directorate was built. Such an approach is also one of the cornerstones of the N.A.C.A. and the 1958 Space Act that authorized NASA.

Bringing the Outer Planets Within Reach

A broad range of technology advancements and alternate mission implementation approaches are needed to allow for the conduct of compelling deep-space missions at various scales including NASA's New Frontiers and Discovery-class missions. For example, low mass avionics and power systems capable of operating reliably at very low temperatures will enhance or enable a broad set of deep space missions. Listed below are six technology areas that are critical to explore our solar system's ocean worlds or complete other compelling science missions outlined in the NRC Planetary Science Decadal Survey.

Radioisotope Power Systems (RPS): Space exploration missions require safe, reliable, long-lived power to provide electricity and thermal energy to the spacecraft and their science instruments. One source of power, particularly for missions far from the Sun, is the Radioisotope Thermoelectric Generator (RTG) that reliably converts heat into electricity through the natural decay of plutonium. RTGs have been safely used on solar system exploration missions since the 1970s, including Pioneer, Voyager, Ulysses, Viking, Galileo, Cassini, Curiosity, and New Horizons. Such systems were also used in the Apollo program. Today, Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) are the only viable RPS option for planetary exploration missions. With a mass of 45 kg, each MMRTG is capable of generating 125 W of power at the beginning of its life. For approximately five years, NASA and the DOE pursued development of the Advanced Stirling Radioisotope Generator (ASRG). With a mass of approximately 20 kg, this system was designed to produce 140 W of power at the beginning of its life while using only one quarter the plutonium of a MMRTG, implying the potential availability of four times the number of systems with current materials. The ASRG achieves it efficiency through precise and rapid movement of a piston; reliably and accurately controlling this movement for the duration of a deep space mission (potentially a decade or more) is the critical breakthrough required for ASRG feasibility. In 2013, NASA greatly scaled back its ASRG activity and used these funds to maintain the DOE production line.

Given the presently planned cadence of deep space missions in need of a radioisotope power system (about one per decade), the reliability issues surrounding the ASRG, and the cost involved, NASA's decision in 2013 was certainly understandable. However, in making this decision, NASA has boxed itself into a future in which expanding the pace of outer planet exploration may not be possible. Compounding this situation, NASA is currently expending little effort on MMRTG alternatives, including the previous system used by Cassini, Galileo and New Horizons which provided about double the performance (W/kg) of the MMRTG. As such, should

our nation decide to increase the pace of outer planet exploration, there may be few, if any, technologies ready for NASA to apply to this challenge. A long-lived Europa lander will certainly not be solar powered; neither will a Europa submarine, or missions to explore Uranus or Neptune, sail the seas of Titan, or follow-up to New Frontiers' discoveries at Pluto. Furthermore, NASA's 2013 decision certainly penalizes potential Discovery class missions more significantly than potential Flagship missions (that can likely afford the mass impact associated with the MMRTG) at a time when we should be doing all we can to enable a diverse suite of low cost exploration missions to flourish. In my view, this is a technology problem whose solution must be addressed as part of plans to expand the exploration of the ocean abodes of our solar system. This investment in a high reliability, high performance RPS must precede the mission development funding. Without this investment, numerous deep space missions are likely to remain unattainable.

Deep Space Atomic Clock (DSAC): Precise timekeeping is essential to navigation. As the Earth and the planets move about the Sun at different rates, an accurate estimation of time is a critical part of obtaining precise position and velocity estimates. Ground-based atomic clocks have long been a cornerstone of deep space vehicle navigation, providing the baseline data necessary for precise positioning through two-way communication. The Space Technology funded DSAC project is developing a smaller and lighter version of the refrigerator-sized atomic clocks used as part of this process today at NASA's Deep Space Network (DSN) tracking stations. Use of an accurate onboard clock eliminates the navigation need to send signals from Earth to a spacecraft and back, optimizing use of the DSN to enable more efficient data return while simultaneously improving navigation performance. DSAC has direct application to gravity science and atmospheric sounding missions and is about an order of magnitude more accurate and stable than the GPS clocks in use today at the Earth, while also being smaller and lighter. Upon completion of a 2016 low Earth orbit demonstration mission, this technology will be ready for infusion on deep space missions in the early 2020s. SMD listed this technology as Government Furnished Equipment in its most recent SMD Discovery call and the DSAC is expected to be included in the same manner in the upcoming SMD New Frontiers solicitation.

Deep Space Optical Communications (DSOC): Because the power required for radio frequency communications increases with the square of the distance, the efficient and reliable return of science data to Earth is a challenge for deep space missions. For missions to Jupiter and beyond, the demands of returning science data to Earth may dominate the power budget of a spacecraft. As we look to accomplish more scientifically ambitious missions to Mars or consider the scientific exploration of Europa and other ocean worlds, a shift to a different communications architecture may be necessary. Through a partnership between SMD and STMD, NASA is incentivizing the flight of a DSOC system aboard the next Discovery mission. The system will provide a factor of ten increase in bandwidth for the same power (and at far lower mass) compared to a state-of-the-art radio frequency communications system. The system under development for this Discovery opportunity will be directly applicable to a Europa mission, providing a factor of 10 increase in bandwidth relative to traditional approaches. More importantly, the DSOC system represents the beginning of a transformation to optical communications that is occurring not only for deep space missions, but also potentially to NASA's Tracking and Data Relay Satellites (TDRS) as well as for commercial communications satellites. Within NASA, STMD is the stakeholder investor across this optical technology

spectrum. Through a partnership with NASA's SCaN Office, other government agencies, and satellite manufactures, STMD will build and demonstrate the Laser Communications and Relay Demonstration (LCRD) in geosynchronous orbit.

Terrain Relative Navigation (TRN): Most planetary landing systems utilize onboard inertial navigation to compute position and velocity based on accelerometer and gyroscope measurements. In TRN, a vehicle's position is estimated by autonomously comparing local terrain measurements (e.g. imagery) with an onboard map. In this manner, the vehicle effectively navigates using the local terrain and can land with great precision relative to local terrain features of scientific interest. For example, recent Mars landing studies have estimated that with TRN, the approximate +/- 10 km Mars Science Laboratory landing footprint could have been reduced to +/- 100 m. This technology may also be fused with science sensors or other sensor measurements to create and intelligent landing system capable of setting down close to scientifically interesting locations, dramatically reducing, and, in the extreme, possibly eliminating the need for significant surface mobility. This technology would significantly improve science return at locales, such as Europa and Titan, where only cursory landing site information may be available. Such a system may enable feasible surface science missions with greatly reduced mobility requirements (and associated cost). In addition to the outer planets, TRN is applicable to Mars landings (this technology is presently under consideration for flight on the Mars 2020 mission) and was baselined in prior plans for human exploration of the Moon.

Ocean Worlds Landing Testbed: Because landing on an ocean world requires overcoming dramatically different challenges than those destinations at which the U.S. has landed previously, development of an ocean worlds landing testbed (analogous to the JPL Mars yard used for rover testing) is needed to allow advancement of the broad range of landing architectures, technologies and capabilities required for safe access to the new and diverse surface and subsurface environments found at these vistas. This testbed would also enable development and testing of ocean worlds surface and subsurface mobility systems (e.g., melt probes).

Heatshield for Extreme Entry Environment Technology (HEEET): Today, many of the same technologists at the NASA Ames Research Center that developed PICA are maturing a woven thermal protection system material capable of withstanding the harsh aerothermodynamic environment associated with flight through the atmospheres of Saturn, Uranus or Venus. This technology development is enabling to several potential missions described in the NRC Planetary Science Decadal Survey. Without HEEET, these missions are significantly constrained by the use of heritage carbon phenolic materials that have not been manufactured in more than a decade. Funded by the Space Technology Mission Directorate, this technology was offered as Government Furnished Equipment in the recent SMD Discovery call and is anticipated to be included in the same manner in the upcoming SMD New Frontiers solicitation. Without this technological solution, it is likely that missions to the surface of Venus, or to study the atmospheres of Saturn or Uranus would not be feasible. The partnership between STMD and SMD to develop and potentially infuse HEEET is representative of how NASA can effectively manage technology development for future missions, allowing potential NASA science missions that otherwise would simply not be possible.

Within NASA today, much of the longer-term technology development work is performed within the Space Technology Mission Directorate, with nearer-term, science mission technology investments largely managed within the Science Mission Directorate. Clearly, this approach requires STMD and SMD to work together for the advancement of planetary science. There is ample evidence to suggest that this relationship is flourishing. For example, the latest Discovery call included the NASA provision of five STMD developed technologies: DSAC, DSOC, HEEET, Advanced Solar Arrays, and a Green Propellant technology alternative to hydrazine. STMD and SMD are also co-funding and number of advanced development efforts. Equally important, without the technology investments contained within the Space Technology budget line, missions to access the Mars subsurface, analyze and return samples from nucleus of a comet, sample the liquid water of one or more ocean worlds, survey the geology of the Venus surface, sail the hydrocarbon seas of Titan, or return to Pluto will likely remain just out of reach of lower cost and potentially higher cadence mission opportunities.

Summary

Planetary exploration is a unique symbol of our country's technological leadership and pioneering spirit. We are fortunate to live in a time and be part of a society that has the capability and sense of wonder to expand humanity's reach from the cradle of Earth throughout the solar system. Working at the intersection of science, engineering and technology, our solar system exploration missions yield a return far greater than the funding invested. The challenges of these missions inspire our children, build the scientific and engineering literacy of our country, and increase our economic and technological competitiveness. We have now completed a first investigation of each major body in our solar system. There is still so much to learn. Fueled by new technological capabilities and mission implementation approaches, compelling scientific discoveries are within our grasp. However, without appropriate technology investment, these dreams will not be realized.

Now is the time to accelerate, not curtail, the pace and scope of our nation's solar system exploration program. Our nation needs to dream big, and achieving large goals is precisely what America has come to expect of NASA's solar system exploration program. Through our exploration missions to date, a major scientific quest focused on fundamental questions of evolution, habitability and life across our solar system's ocean worlds has begun to emerge. Coupling our scientific drive with investment in the critical technologies required to accomplish these future missions at a risk posture commensurate with robotic exploration is the only way to achieve the grand objectives of these future missions within reasonable cost and time scales.

Investments in NASA technology produce benefits far beyond the Agency's missions, influencing the commercial sector and society as a whole. Positive outcomes that are likely from an investment in the technologies required for our planetary science program include economic, national security, global leadership and societal benefits. As illustrated by some of the examples I have discussed today, these advances will serve to enable solar system exploration missions that would not otherwise be possible, spark a technology-based economy, and highlight internationally our country's scientific innovation, engineering creativity and technological skill.

Dr. Robert D. Braun serves as the David and Andrew Lewis Professor of Space Technology at the Georgia Institute of Technology. He is also the founding director of the Georgia Tech Center for Space Technology and Research. He has been a member of the Georgia Tech faculty since 2003 and leads an active research and educational program focused on the design of advanced flight systems and technologies for planetary exploration. He previously served as a leader and senior manager for several engineering organizations at NASA. In 2010-2011, he served as the first NASA Chief Technologist in more than a decade. In this capacity, he was the senior Agency executive for technology and innovation policy and programs and was responsible for creating the NASA Space Technology programs. From 1989 to 2003, he was a member of the technical staff of the NASA Langley Research Center. In 2012, Dr. Braun co-founded Terminal Velocity Aerospace, LLC, a small business focused on developing a suite of re-entry devices to improve orbital debris hazard prediction and promote space utilization. Dr. Braun presently serves on Advisory Boards for the Jet Propulsion Laboratory, Skolkovo Institute of Science and Technology, Planet Labs Inc., and the Planetary Society. He served as a member of the USAF Scientific Advisory Board from 2012-2014. He received a B.S. in Aerospace Engineering from Penn State, M.S. in Astronautics from the George Washington University, and Ph.D. in Aeronautics and Astronautics from Stanford University. He is a member of the National Academy of Engineering, Vice Chair of the NRC Space Studies Board, an AIAA Fellow, and the Editor-in-Chief of the *AIAA Journal of Spacecraft and Rockets*. He is the author or co-author of over 275 technical publications in the fields of atmospheric flight dynamics, planetary exploration, multidisciplinary design optimization, and systems engineering. He lives on a small farm in Newnan, Georgia with his wife Karen and is the proud father of Zack, Allie and Jessica Braun.

Chairman SMITH. Thank you, Dr. Braun.

Now, I'll recognize myself for questions.

And, Dr. Grunsfeld, let me address the first one to you, and that is if Congress restored the proposed $70 million in cuts that the Administration has recommended for Planetary Science, what could you use that money for, that $70 million?

Dr. GRUNSFELD. You know, one area that the Decadal Survey prioritizes—as do we—pretty highly is our Discovery and New Frontiers Program. As you know, the Pluto New Horizons mission was the first in our New Frontiers program and wildly successful I would say is an understatement. And we are just in the process now hopefully in September before the end of the fiscal year selecting investigations for the next Discovery program.

Chairman SMITH. Right. Right.

Dr. GRUNSFELD. And so we would be up to keep those on track and increase the cadence with——

Chairman SMITH. Okay.

Dr. GRUNSFELD. —increased funding.

Chairman SMITH. Thank you, Dr. Grunsfeld.

Dr. Stern, let me offer you a slow pitch over home plate, and what do you think is the greatest discovery of the many discoveries made by New Horizons so far?

Dr. STERN. If you'll allow me, Mr. Chairman, I'd like to suggest that there are two very important discoveries. One is scientific and that is the one that I alluded to, that it's very clear that we do not understand the interior workings of small planets. Previously, we found many active bodies, satellites, for example, of the giant planets that showed activity after these many billions of years, but we always had an out scientifically in that they derive their energy in large measure from tidal heating, which is specifically a result of being in orbit around a giant planet and in a giant planet's satellite system.

Pluto is completely isolated. It does not generate any tidal energy with its interactions with Charon because they have reached tidal spin equilibrium. And yet somehow this world is active after 4–1/2 billion years. And just like a small cup of coffee will cool off much more quickly than a big vat of coffee, small planets should cool off, and yet it has not. And this is a major challenge to the field of planetary science to understand how this could be, and it's a demonstration that only could be made by going to Pluto, which New Horizons has now done.

I want to say the other big discovery in my view is a level of public interest in exploration, which went completely viral. I think people really like frontiers and the United States is in a great position to extend soft power projection through just this kind of space program.

Chairman SMITH. Yeah, I agree with you. I love to see the media coverage and it shows that people are fascinated by exploration. And I liked your turn of phrase a while ago, "the power and attraction of exploring the unknown." I think that does appeal to people.

Dr. Russell, NASA is tasked with the responsibility of cataloging our near-Earth objects with diameters greater than 140 meters. In what way does the Dawn mission help us understand both the risk and the possibilities of detecting those near-Earth objects?

Dr. RUSSELL. Dawn is far out of the line of fire so it does not really add very much to that particular objective. However, that— there are a lot of things that we are doing both by observations from the Earth and observations from space that will enable us to solve those particular problems. But Dawn is more in the area of what Dr. Stern just told us about, is trying to understand how those midsize bodies were formed and still are active today in the case of Ceres and a little bit in the case of Vesta, too. So we're really looking at a spectrum of bodies in the solar system.

Chairman SMITH. Okay. Thank you, Dr. Russell.

Let me address my last question both to Dr. Pappalardo and Dr. Braun. And this question is asked not only on behalf of myself but on behalf of my Texas colleague John Culberson. I don't know of any Member who has a greater interest in Europa than John does, as you probably know and probably have talked to him about it firsthand.

But the planned mission to Europa is in part I think designed to try to detect any possible form of life. And, Dr. Braun, you mentioned the need to explore our ocean worlds. I think Europa offers one of the best possibilities of doing that. Dr. Pappalardo and Dr. Braun, how could that mission to Europa inform our understanding or enable us to perhaps ferret out any type of form of life there?

Dr. PAPPALARDO. What we really are trying to get at at Europa first is, is it a habitable environment? We think it is. We want to understand the potential ingredients for life. Want to confirm an ocean, we want to understand the chemistry and whether that is conducive to life, and we want to understand is there an energy source for life in Europa's ocean? And by that I don't just mean tidal energy but is there a chemical imbalance that can allow for chemical reactions to power life? This mission wouldn't really go to search for life exactly but to understand the habitability, kind of like the initial Mars rovers did.

Chairman SMITH. Right. And, Dr. Braun?

Dr. BRAUN. The Europa's surface is planetary science Disneyland. And flying above it and studying it from above is like taking a three day drive across country from here to Disneyland and staying in the parking lot, right?

So I believe strongly, you know, just like in our Mars exploration program we have had orbiters and we've had landers, and the two together have what's advanced Mars science. So if we truly want to advance Europa's science in the same way, it's going to take a combination of flyby/orbiter and landed assets. Until we touch the surface, we won't know.

Chairman SMITH. Okay. Thank you both for your responses.

And the gentlewoman from Maryland, Ms. Edwards, is recognized for her questions.

Ms. EDWARDS. Thank you very much, Mr. Chairman. And thank you to the witnesses.

I have to tell you I feel like highly undereducated here today, and I hope that the young people who are watching and listening and those who are here understand that today we have some of the most amazing planetary science minds available in the world, and it's just a delight to be able to have you here with us today.

I've been very curious and looking at the lifecycle of projects and missions, because I think here in the Congress sometimes we deal with things that are very, very short-term and we're thinking about the next appropriations cycle, a year or two years, and it occurs to me as you are talking about each one of these missions, that in fact going back to the recommendations that come out of the Decadal Survey and the work that actually precedes that so that something actually makes it on the list to the time that we do all of the work that it takes from a scientific perspective, from an engineering perspective to get a mission underway and then to look at the results and figure out what's next, it's a really long lifecycle.

And I appreciate your sharing with us today because I think sometimes we don't understand that it's a long lifecycle and we have no idea sometimes at the end or the near end and what we may have been able to discover or predict at the beginning. And from a funding standpoint, and we've all talked about this, I think the Chairman has mentioned it as well, it becomes hard to project what it is that we believe we're going to get for the dollar that we spend.

And so I would like each of you, if you could, just take an opportunity, beginning with Dr. Grunsfeld, to talk to us about that lifecycle and about the recommendations that come out of the Decadal Survey and how that's used and how we use the work of the Academies to inform what we're doing even if we can't see it for 25, 30, 50 years in the running.

Dr. GRUNSFELD. Well, thank you very much. Certainly we rely very heavily at NASA and science on the community consensus that's built in the process of developing the Decadal Surveys. And in the last couple of planetary science Decadal Surveys, we got really excellent advice. The Pluto mission was highly ranked and we've now achieved that and it's continuing now into the Kuiper belt for—to make new discoveries.

In more recent years, a Mars sample acquisition mission was the highest-rated objective, and of course we started that. That's the Mars 2020 mission. And the second-highest priority in the flagship-class missions was our Europa mission, to go and study Europa, and we've now started that, and then cadence in Discovery and New Frontiers, which we've talked about and research and analysis, and so we're doing our best to try and select this year discovery missions to go on for the next phase. It'll be a two-part competition. So we do rely on that and I think, you know, the report card is we've been doing a pretty good job. And the science has been really spectacular.

Ms. EDWARDS. Thanks.

Dr. Stern, maybe you could tell us. I understand that in the early 2000s NASA actually canceled a previous mission concept in exploring Pluto because of anticipated costs and a New Horizons mission that actually almost never came to be. Can you tell us what turned that around? What are the lessons that we learned and what are your reflections had we not been able to go forward from that point?

Dr. STERN. Well, thank you very much for that question. It is true. There were a series of Pluto missions that were studied but never started in large measure because those missions got a little

bit out of control on cost and the agency had to make fundamental decisions about carrying—executing the remainder of the program. When the last of those was canceled in 2000, there was a tremendous public outcry, the planetary society, individuals in the public, big letter-writing campaign, and a very strong response from the advisory committees to the Science Mission Directorate and its predecessor, the Office of Space Science, which convinced the agency to instead compete the mission. And it was a result of that competition that New Horizons came to be. We proposed that as a team between the Southwest Research Institute and the Applied Physics Lab of Johns Hopkins University.

However, the funding that enabled the build and flight of New Horizons only came as a result of a recommendation from the Decadal Survey that this should be number one on the runway for medium-priority missions and so-called new frontiers missions that Dr. Grunsfeld referred to.

So in my view the Decadal Survey process is very important but it's also very impressive how well it works within the political and policy sphere as well because when that mission was recommended as a top priority, it did unlock the funding that made this possible. And as you can tell both from the standpoint of public interest, as well as the general good feeling in the public about our being able to accomplish important things in our time, as well as the science that's coming out of New Horizons, none of those three things would have been possible had it not been for that Decadal Survey and the competitive process that we were able to win as a result.

Ms. EDWARDS. Thank you very much.

Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Ms. Edwards.

The gentleman from Oklahoma, Mr. Lucas, is recognized.

Mr. LUCAS. Thank you, Mr. Chairman.

Dr. Stern, I represent the northwest half of Oklahoma, and while we live on a very watery planet, water is always an issue of great importance in my neck of the world. Discuss for me a moment this appearance—it appears that we have a mountain of ice water perhaps on Pluto. I mean from my perspective and from the perspective of my constituents, with a long enough timeline, anything's possible if you have water. Talk for a moment about the significance of this find.

Dr. STERN. Sure, happy to. Well, let me start by saying, you know, prior to the arrival of New Horizons, the vast imagery that we were able to obtain was using the Hubble Space Telescope, and thank you, Dr. Grunsfeld for making that possible. Those images had a resolution of several hundred miles per pixel. We're now in the ballpark of several hundred meters and New Horizons has data on board that are still substantially better.

The very first medium-resolution images that we returned just days after the flyby revealed steep topography on the surface of Pluto, those mountains. Now, the primary chemical constituent on the surface of Pluto is molecular nitrogen, condensed—the same stuff that we are breathing right now. That's a very soft material and it can't support strong topography. The inference of the steep topography is there must be a much stronger material that can

support mountain building and construction, and water ice is really the only plausible candidate for that in the Pluto system.

We've known for a long time that probably 1/3 of Pluto's entire mass is water ice. What this has taught us is that that ice is very close to the surface and that the nitrogen and the other things that we've observed spectroscopically are just a frosting of the near if you will on the top, and the water lies right below.

Mr. LUCAS. That said, you mentioned, too, the continuing mission of New Horizons. Based on the fuel system in it, how long will the vehicle be viable as it continues? How many years would you guess the viability of New Horizons to be?

Dr. STERN. Well, New Horizons is very healthy. We have a spacecraft that features completely redundant avionics propulsion system and other features so that it's very reliable. And we're not using any of the backup systems. Our primary limitation on New Horizons is a result of the radioactive decay of plutonium that powers the spacecraft from an electrical standpoint. Currently, that device is generating about 200 watts of power, and it's decaying at the rate of about 3–1/2 watts per year, which is exactly as predicted. New horizons can operate from that device for about 20, possibly a little longer, years into the mid- or late 2030s.

Our extended mission by contrast would involve a flyby of the Kuiper belt building block of planets like Pluto in 2019, so well within our capability.

Mr. LUCAS. One last question, and I direct it to the whole panel. We talk about the great success of putting landers on the various planets and the potential to address the potential oceans that might be under Europa and other planets. Discuss for a moment the protocols that we use so that we don't seed planets as we go along so to speak so that we don't take things with us when we get there.

Dr. GRUNSFELD. So we have—I don't want to speak to much requirements-ese, but we have actually a Planetary Protection Program and documents and a Planetary Protection Officer that reviewed the missions, and it's particularly important for missions like Europa, for our Mars Landers, we're having a discussion now about the cleanliness of Mars, Curiosity's wheels so that we might go to someplace that, you know, potentially has signs of liquid water, and so we analyze that in great detail. We clean the spacecraft and we try and do our best not to send Earth life to places that, you know, it might be able to take hold. It's a big deal for us.

Mr. LUCAS. And in a water world, even a greater issue, correct, Doctor?

Dr. PAPPALARDO. Yes. So for Europa, the plan is to bake the spacecraft, to heat the spacecraft and its components to a temperature that would kill off any microorganisms that might be on board, and the same for the instruments. And that of course has to be done in a way that is safe for the instruments, that it doesn't damage them, and then we protect the spacecraft and keep it clean before launch.

Mr. LUCAS. Thank you very much, gentlemen.

I yield back my time, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Lucas.

The gentleman from Colorado is recognized for his questions.

Mr. PERLMUTTER. Thanks, Mr. Chair.

And, gentlemen, we applauded the New Horizons flyby of Pluto. The applause really goes to all of you. I mean I know personally I'm just very proud of what NASA's been doing and about the exploration of our solar system and hopefully someday our Universe. And the comments that all of you have made about us being explorers in our hearts and, you know, as part of our DNA as Americans, I think as humans. And just thank you for being at the forefront of all of this.

I'm basically speechless in terms of asking you the right questions. I'm very happy that a couple of you have solid connections to Colorado and to the University of Colorado. That's one of my favorite things.

I guess the question I'd like to ask is, as we do these things, do you have students, do you have people following in your footsteps? Because this seems to be moving at greater and greater speeds as we're going farther and farther with our exploration or more focused with our exploration. So, Dr. Pappalardo, Dr. Braun, why don't I start with you guys and then I'm going to work to the other end.

Dr. PAPPALARDO. Sure. Absolutely. I have a laboratory of several interns, summer interns right now back at the Jet Propulsion Laboratory who's hopefully watching this on the web and who are extremely excited about Europa. There are some folks who have come here today from the Air and Space Museum who are interns who are very excited about it.

The students who are in elementary school today will be in graduate school at the time that this mission is probably arriving at Europa, and those are the folks that this mission is really for. Those are the folks we want to inspire and get involved as the next generation of explorers.

Mr. PERLMUTTER. Thank you. Dr. Braun?

Dr. BRAUN. Yeah, if I could add to that, as a faculty member in the College of Engineering at Georgia Tech, I can tell you with certainty that these kinds of missions, whether they're at Mars, whether Europa or Pluto, they're a natural draw to more and more students in engineering and in science. They inspire young people into educational paths and careers——

Mr. PERLMUTTER. They even inspire lawyers like myself.

Dr. BRAUN. Well——

Mr. PERLMUTTER. So——

Dr. BRAUN. —we can get one or two of those as well, but we want more and more engineers and scientists——

Mr. PERLMUTTER. Okay.

Dr. BRAUN. —if that's okay. But there's no doubt that at Georgia Tech and at universities around the Nation that people are—that young people are watching and that young people are inspired into our space program because of these types of feats, and that they lead frankly to economic national security and a large range of societal benefits as well.

Mr. PERLMUTTER. Thank you. Thank you.

Dr. Stern, it's good to see you. I don't even know where to start on the Pluto mission other than you—that mission started when I

started running for office nine years ago. In the process—let's talk about the engineering, and, Dr. Braun, you're welcome to chime in here, but the engineering is a marvel for me, the fact that basically the math, the science, the engineering all came together for you to hit a spot out there that's like a millimeter across and me being able to hit it on that wall. I mean can you talk about that a little bit, those parts of the mission?

Dr. STERN. Well, thank you very much, Congressman Perlmutter. The New Horizons mission is a technological marvel and in miniaturization in terms of the accuracy of the flight path that we had to hit, we had to fly through a 60 by 90 kilometer window after a 3 billion mile journey. That's about equivalent of throwing a ball from Los Angeles to New York and landing in——

Mr. PERLMUTTER. The strike zone.

Dr. STERN. —a can of beans. And we were a little bit early arriving after 9–1/2 years. We arrived 91 seconds early, which is equivalent to L.A. to New York on a commercial airliner 4 milliseconds off schedule. It's an amazing testament to the technology that's been developed in terms of ground-based tracking, as well as the spacecraft technology that we can do these things and that we can miniaturize the instrumentation to this level and that the spacecraft can fly autonomously using hibernation techniques as an onboard intelligent pilot. All of those things and more are amazing aspects of the technology we develop.

But most impressive to me is the fact that New Horizons was developed and flown in its entirety soup to nuts for 1/5 of the cost of the Voyager program on an inflation-adjusted basis. So we have really learned to do these things in NASA that are not only technologically impressive but get a lot more bang for buck than at the outset of the space program.

Mr. PERLMUTTER. And my time has expired. I'll yield back but, Dr. Russell, Dr. Grunsfeld, thank you, too. I'll get to you next time. Thanks.

Chairman SMITH. Thank you, Mr. Perlmutter.

The gentleman from Oklahoma, Mr. Bridenstine, is recognized for his questions.

Mr. BRIDENSTINE. Thank you, Mr. Chairman. What an exciting testimony from all of you. I'm thrilled about it as a Member of this Committee.

I wanted to ask Dr. Grunsfeld, I read in Space News recently about this cryogenic compressor assembly for the James Webb Space Telescope, and it's been delayed and of course the costs have gone from 22 million to 150 million. I was wondering, can you shed light on how that happened and ultimately what the impact that will be for the James Webb Space Telescope?

Dr. GRUNSFELD. Sure, I'd be happy to. First of all, I'd like to report that the cryocooler assembly has been delivered on dock to JPL. I think it was two days ago. I was just trying to remember. It might've been three days ago. And so it's complete. It's been delivered from Northrop Grumman to JPL. JPL will do the acceptance testing and then it will be delivered to the Goddard Spaceflight Center and integrated in with the rest of the assembly.

When the—first of all, the James Webb Space Telescope is—we've talked about technological tour de force, you know, a number

of inventions that had to occur to be able to build the telescope and now they're all complete was really phenomenal. This is a telescope that will go a million miles from Earth and will achieve a temperature, the actual optics and the instruments that's roughly the temperature of Pluto, and it needs to do that to be able to see these very dim objects at the edge of our universe and to study exoplanets.

One part of that was this very innovative cryocooler. The team that proposed it built an engineering unit, which was bolted together and showed that they can make a cryocooler to get these cold temperatures. What they failed to do was to demonstrate they knew how to manufacture one for flight, so it was bolted together instead of welded, some of the materials were different, and in the process of figuring out over, you know, the better part of a decade how to actually manufacture it for the flight unit, they encountered a lot more difficulties.

Thank you very much to Congress for funding us appropriately to be able to afford, you know, the spending on that cryocooler in our reserves, and our unfunded part of the budget so that we can accommodate this problem. Other problems—you know, other assemblies went smoothly and so we applied our reserves on this, and it has since been delivered so we're past that. That really was a difficulty in manufacturing.

Mr. BRIDENSTINE. To ask on that point that you made regarding funding, it looks like funding for next year for the James Webb Space Telescope is being cut per the President's budget request by $25 million. Is that—and of course the money is going other places. Is that a problem for this issue? Are we going to have more issues like this where we have unexpected costs that creep up? I just don't want to put the James Webb Space Telescope at risk.

Dr. GRUNSFELD. Yeah, me neither. It's a very high priority for us. It's going to make amazing discoveries. One of the things that the James Webb Space Telescope will be able to do is follow up on the Pluto New Horizons observations as it goes sailing off into the Kuiper belt.

The President's proposed budget is exactly what the project asked for, so that's just the normal change in budget as they retire some of the development activities and go into integration and tests. So we actually asked for exactly what we need and we got that as a request.

Mr. BRIDENSTINE. Okay. Well, that's a—that was my major question. Thank you for answering, and thanks, Chairman.

Chairman SMITH. Okay. Thank you, Mr. Bridenstine.

The gentleman from Texas, Mr. Babin, is recognized.

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman.

What a fascinating—probably the most fascinating committee meeting I've been to in my Congressional career so far.

And, Dr. Grunsfeld, let me—let me just say congratulations to all of you for playing a part in this huge endeavor that we've just seen successfully into, actually kind of a beginning to.

But, Dr. Grunsfeld, the Johnson Space Center, which I represent in Houston, is home to the Astromaterials Acquisition and Curation office. This office is responsible for the curation of extraterrestrial samples from NASA's past and future sample return

missions. The mission—their mission includes the documentation, preservation, preparation, and distribution of samples from the moon, asteroids, comets, the solar wind, and the planet Mars. Would you please explain how this facility will contribute to future planetary science missions going forward and how this unique and important capability will be maintained?

Dr. GRUNSFELD. This astromaterials facility at the Johnson Space Center really is a national treasure. As you said, this is where our moon samples are kept, many meteorite samples; samples from comets will be, you know, stored there. Our OSIRIS–REx mission is going to perhaps return as much as 1.2 kilograms of samples. We are partnering with the Japanese on their sample return mission and we'll have exchanges of materials. This is, you know, really our treasure trove of, you know, deep space samples.

And our Mars 2020 Rover, which will be collecting samples, you know, eventually we hope to get those back to Earth and that'll be the center of activity. And so it really is a science warehouse if you will. As much as the data that comes back from Pluto New Horizons will be stored on servers, you know, this is our central warehouse for that.

Mr. BABIN. Right. Okay. Thank you very much. And I also have one more question for you if you don't mind. NASA's Space Launch System or the SLS will be the most powerful rocket in the world and will carry humans on exploration missions beyond Earth's orbit. Given its tremendous lift capability, what advantages would SLS provide for planetary science and what types of missions might be enabled by SLS? Although today I've heard that we don't need these huge machines as much as we have in the past with some of the lightening up of a lot of these instrumentation. But what is your thoughts on the SLS and what the capabilities of the future would be?

Dr. GRUNSFELD. My view is that the Space Launch System will be transformative for science. And let me say that Pluto New Horizons, even though it was lightweight as much as the team could do, still required the largest Atlas rocket that could be built so—and to be able to get that speed and to zip out to Pluto.

The mission to Europa, you know, we are currently designing the spacecraft to fit on any of a variety of launch vehicles, but we're including the Space Lunch System in that trade space because the trip to Jupiter to get to Europa is a very long trip. On the biggest Atlas rocket, it would take just shy of eight years to get to Europa and zipping around the inner solar system, getting sling-shotted out. On the Space Launch System, it would be under three years. And this is one of those rare cases where time really is money because in that extra cruise time, you know, we have to maintain an engineering team and a science team and a spacecraft while it's in cruise even if we hibernate it, you know, and that's something that, you know, also delays the science.

A large launch vehicle like the SLS with a large faring, the container that the spacecraft goes in, can also be enabling for things like deep space astronomy, launching a larger telescope, perhaps even launching telescope parts that astronauts could assemble to build a telescope that could search for atmospheres around nearby worlds.

Dr. STERN. And if I might, I don't want my earlier remarks to be misconstrued, I really appreciated your question, but let me say that for a mission like New Horizons, which is a simple flyby, the first reconnaissance of that miniaturization really helps us, but for the next steps up when you want to do orbiters and landers and sample return like the ambitious missions that have been spoken about, you need to carry a lot of fuel. And there's no way to lighten the fuel. You need it so you can come to a stop on that planetary service or an orbit, and SLS is going to really help us enable those kinds of deep space missions, including I hope one day a return to the Pluto system in the Kuiper belt.

Mr. BABIN. Thank you, Dr. Stern. I appreciate you making an addition to that. I appreciate all the witnesses, very fascinating. Thank you so much.

Chairman SMITH. Thank you, Mr. Babin.

The gentleman from Ohio, Mr. Johnson, is recognized for his questions.

Mr. JOHNSON. Thank you, Mr. Chairman.

Dr. Grunsfeld, I represent the 6th District of Ohio, and although NASA Glenn is not in my district, being the only member from Ohio on the Science, Space, and Technology Committee, I'm very interested in what's going on at NASA Glenn. And I know they've been involved in the past in the Advanced Stirling Radioisotope Generator program. There's concern in the science community about the inventory of plutonium 238, as you know, the fuel which powers long-distance robotic spacecraft. Last year, NASA canceled the—its program to design the Advanced Stirling Radioisotope Generator that would use far less plutonium 238 per mission. So in place of this program, what is NASA doing to develop the next generation of nuclear power sources for exploring the outer planets?

Dr. GRUNSFELD. Thank you. First of all, what we canceled last year was the flight portion of the Advanced Stirling Radioisotope Generator, which—so a flight model to use on a mission. We've kept the technology funding so that they can continue to advance and do life-testing on the technology. What we determined is that the cost was growing for the flight unit very rapidly and it wasn't clear that we'd converge. But we want to keep that technology going so we're continuing to fund that.

At the same time we're working with the Department of Energy very closely on production of new plutonium 238. We have an existing stockpile and the new plutonium will be mixed with the old plutonium to create fuel for future missions. That could include discovering new frontiers. We have enough fuel currently on hand for our Mars 2020 mission. We've made the decision partly based on the great success of the Juno mission so far to go with solar. It's actually a better match for the Europa mission, but we certainly are going to increase the production and maintain our capabilities for building our multi-mission radioisotope thermal generators.

We're also investing in technology that will allow the current fuel to be more efficient, new thermocouples to up the efficiency. And all of that work, all of what I described is being done at the Glenn Research Center.

Mr. JOHNSON. Okay. Now, staying on the budget theme for a minute, how does the fiscal year 2016 funding for NASA's Planetary Science Division impact—you mentioned the New Frontier program. How does it impact the scheduling of the next New Frontiers competition?

Dr. GRUNSFELD. The next New Frontiers competition we're hoping—actually, Jim Green is here. I am—we're hoping to put out a solicitation in roughly the next year. You know, the funding level in the fiscal year 2016 request doesn't allow us to be particularly aggressive, and so that's something that would then be launching sometime early in the next decade.

Mr. JOHNSON. Okay. All right. And for any of the rest of you gentlemen, how have budget cuts to NASA's Planetary Science Division impacted the scientific community, particularly the next generation of planetary scientists? Anyone have a concern?

Dr. PAPPALARDO. Why don't I say a word just for my colleagues who rely on the research and analysis program. There are a lot of young scientists who question whether they can stay in the field because of the kinds of cuts that have happened in planetary science. And then when we don't see new missions coming along and finally Europa is coming along, we don't see the kind of research programs that go along with those missions. So something like the Europa mission brings along with it a large cadre of science and some funding to do science and promote research in that area. But, yeah, I just want to raise a flag regarding that research and analysis program because there are a lot of excellent young scientists who feel like, well, maybe they should just leave this field.

Mr. JOHNSON. Okay. Dr. Grunsfeld, back to you. NASA backed out of the ExoMars mission leaving Russia to partner with Europe. NASA's InSight mission, as we know, is an American spacecraft but it carries mostly European instruments. How is the NASA's Planetary Science Division strategically approaching international cooperation on future missions?

Dr. GRUNSFELD. I think, you know, the first thing is that when we changed our participation in ExoMars 2016, the trace gas orbiter, and ExoMars 2018, their lander, you know, we at the time were providing a launch vehicle, some instruments, and a landing system. You know, in tight budgets, you know, it was decided that, you know, providing those capabilities really wasn't advantageous to the United States. However, we're still deeply involved in both missions and we're providing a lot of support. We're providing instruments, some technical capability for the trace gas orbiter, and we're actually providing from the Goddard Spaceflight Center the Mars Organic Molecular Analyzer, which is the front end for the—the highlight instrument on the lander. And so we have U.S. scientists deeply involved in the ExoMars, both '16 and '18 opportunities.

And we're thrilled that the Russians have come on board, that it's now a stronger partnership. About 90 percent of all of our planetary science missions have significant international partnerships and, you know, a good example is the Cassini spacecraft, which not only has scientists participating in multiple instruments but they provided a whole probe, the Huygens probe, which descended into

Titan's atmosphere. The Mars 2020 mission, again, a lot of international partnership.

Mr. JOHNSON. I'd like to go deeper but my time has over-expired.

Chairman SMITH. Thank you.

Mr. JOHNSON. And, Mr. Chairman, I thank you for the indulgence.

Chairman SMITH. Thank you——

Mr. JOHNSON. I yield back.

Chairman SMITH. Thank you, Mr. Johnson.

The gentleman from New York, Mr. Tonko, is recognized.

Mr. TONKO. Thank you, Mr. Chair, and thank you to a very distinguished and impressive panel of witnesses. And thank you for reminding me and hopefully all of us of where vision, leadership, and tenacity can truly take us.

Forty-six years ago the world watched as Neil Armstrong and Edwin Buzz Aldrin and Michael Collins' journey to the moon captured humanity's imagination and inspired a generation to reconsider the possibilities of space exploration. In those years leading up to the moon landing, I watched with great interest as a high schooler the race between the United States and the Soviet Union for spaceflight supremacy. Hearing and learning about the work you do, the matters you study, and certainly all of us were captured by this and are in awe of what we will explore and learn in the coming years.

Back with the space race of the '60s, we had a young president who challenged the Nation to land on the moon, and we had a passionate resolve to use science and engineering to beat our rivals. And it's been years of investing and innovating that enabled America to be a leader in this endeavor to be the first to land on the moon and to continue with space explorations.

One of my biggest concerns is that, as a nation, we may be losing sight of what we can achieve in terms of space exploration and that in turn we may be missing opportunities to inspire the next generation of scientists and engineers. We must retain the will to explore, as well as the human infrastructure needed to make the proposed missions a reality.

So for any of you, I would ask, do you believe that the public is aware of the many missions and discoveries that we're making as a nation? And I would reference this basic New Horizons Pluto mission. Is there that growing interest that we saw in the '60s in your opinion?

Dr. STERN. Well, if I may answer that on behalf of my experience with New Horizons in recent weeks, I've seen a tremendous outpouring from the public both in talks that I've given like at the Intrepid Museum in New York this past weekend, as well as through email and social media, I've seen an enormous number of younger people, young people saying I've never seen anything like this; we can do great things in our time. It makes me feel good about our generation that we live in a time like this. And I've seen people actually tell me that they were moved to tears about the New Horizons flyby. I think we can inspire. And the program that's coming in the future I think can equally inspire.

Mr. TONKO. Thank you. And anyone else that wants to——

Dr. GRUNSFELD. I would just say that when we landed the Curiosity mission on Mars almost three years ago, we had, you know, amazing response from the public. There were crowds in Times Square watching on the large screens. This is for an event that's just a mission landing on Mars, not even the great science that came out afterwards.

We—because of the power of social networking, we have the ability now to measure the response for events like Pluto New Horizons, like the Mars Curiosity landing, even just, you know, announcements from NASA of discoveries of a cousin system to our own solar system, a sun like our sun and a planet somewhat like our Earth, and we find, you know, that ridiculously large numbers of people are following this and worldwide, billions and billions of impressions, you know, the number of—the circulation times the number of stories that far exceeds the number of smart devices and computers and phones and things. It's really quite remarkable.

And what I think is most encouraging is that when we have an event like the flyby, that's excitement, that's exploration, that's the human endeavor, and we get this great following. What I find most encouraging is that once the science starts coming out, the following is still there. The inspiration is working.

Mr. TONKO. Well, you know, the—many are concerned about our under-producing the engineers we need for society here in the United States. A commitment for this to continue and to grow in the exploration area smacks of research investment amd human infrastructure development. What would you advise this Committee, this panel to do in regard to research investment and growing the scientists and engineers that we obviously will require?

Dr. GRUNSFELD. Well, I'm very appreciative of the efforts of this Committee and of the Congress in supporting our basic research activities. This is fundamental research, you know, exploring the limits of human knowledge. But these are very hard things to do. Pluto New Horizons as a mission was a very hard mission to implement. When we try and do these very hard things, that's when we push engineers, push scientists to expand their own frontiers, which advances our nation technologically, industrially. You know, these—this is one of the reasons why we do this and why it makes our nation so strong. A byproduct is it does inspire the Nation and the world, which is also something we want to do.

Mr. TONKO. Thank you. I believe I've exhausted my time so I yield back, Mr. Chair.

Chairman SMITH. Thank you, Mr. Tonko.

The gentleman from Louisiana, Mr. Abraham, is recognized.

Mr. ABRAHAM. Thank you, Mr. Chairman. And certainly thank you, gentlemen, for being here. I'm privileged to be among rocket scientists.

I guess the question to you, Dr. Grunsfeld, is first. It's nice to have a Planetary Science Division. And certainly this research and these flybys and all this wonderful discovery that the panel has brought to light today ignites excitement and it stimulates young people. What programs does NASA have from the K to 12 level not only for the educators but for the students themselves to continue that excitement and to get those engineers and scientists that you guys need?

Dr. GRUNSFELD. Well, I think any of us would be very hard pressed to go into a K through 12 classroom and not see evidence that, you know, NASA's education programs and specifically the education programs that we support in the Science Mission Directorate that we don't reach from the scientist to teachers, master teachers, pre-service, in-service teachers, to the students in the classroom. We do this through both formal programs and informal programs.

And so this is part of the DNA if you will of scientists that are funded by NASA programs. Twenty years ago or so, you know, NASA sort of had to twist scientists' arms to get involved in education. Now I find that young postdocs, graduate students, young professors, not only do they really want to involve themselves in the broader education effort, they want to do more than we can possibly fund and they do. And it really is this broader public engagement that our scientists are doing that's part of the strength of the current science program at NASA.

Alan?

Dr. STERN. Well, I'll add—first of all, I'd like to echo everything that Dr. Grunsfeld said, but there are other aspects to this as well, and I'll just highlight two. One are the role models that we can provide from the science teams when you have a viral event like New Horizons. Our science team contains scientists, you know, as young as in their mid-20s, brilliant scientists out of institutions like Stanford and MIT and other institutions that can go out into the classrooms and really connect. Those are role models.

And then secondly, on New Horizons, we pioneered something very interesting. We are actually the first planetary mission to carry a student-built experiment to give the students in that instance an opportunity not just to learn about how planetary missions are done and how the science is done but to actually have a hands-on experience and ownership to fly something, in this case, across the entirety of our solar system and to make a little history.

Mr. ABRAHAM. Okay. All right, thank you. Just a quick question and anybody can answer this. Going back to a previous question about international cooperation, what countries out there besides of course the United States are stepping up to the plate that will become leaders in exploration that you guys see coming down the pike?

Dr. GRUNSFELD. I think in part because of the very strong cooperation that many countries have had with the United States, other countries, agencies of countries have been able to put together programs that are very strong and in particular the European Space Agency, as evidenced by the recent Rosetta mission and the Philae lander on a comet, you know, incredibly exciting, daring, and successful. So there's no question that other countries aspire to have the kind of capabilities.

I think one of the really important things is they aspire to do that but they also look to partner with us, and I think as long as they continue to do that, we're in pretty good shape.

Mr. ABRAHAM. Okay. Anybody else? No? Okay.

Dr. Grunsfeld, when does NASA anticipate requesting funding for another flagship mission? When you guys see coming to the table again?

Dr. GRUNSFELD. Well, certainly, we've—you know, we've requested funding for the Europa mission——

Mr. ABRAHAM. Right.

Dr. GRUNSFELD. —for the Mars 2020 mission. I think it's going to be the next Decadal Survey that queues up the priority for what we do after that. In the meantime, and it's already in our budget, we have some very exciting ideas for discovery class missions that are in the queue and we have, you know, certainly many ideas for New Frontiers missions. But I think with the Mars 2020 lander and the Europa mission, you know, our ticket is pretty full right now——

Mr. ABRAHAM. Good.

Dr. GRUNSFELD. —and it's pretty exciting.

Mr. ABRAHAM. Okay. Thank you, Mr. Chairman. I yield back.

Chairman SMITH. And thank you, Mr. Abraham.

It occurs to me I should have done it earlier but I want to recognize a colleague of ours who has joined us, John Culberson of Texas, a Member of the Appropriations Committee. And as I mentioned a while ago when I asked a question on his behalf about Europa, I don't know if anyone in Congress who has a greater interest in that moon than Representative Culberson. So, John, I appreciate your being here today. This is indicative of his long-standing interest in space in general and Europa in particular, so thank you for being here.

The gentlewoman from Oregon, Ms. Bonamici, is recognized.

Ms. BONAMICI. Thank you very much, Mr. Chairman, and thank you to the witnesses for being here. Good to see you, Dr. Grunsfeld.

I apologize for not being here to listen to your testimony. I was in another hearing but I did review it before the hearing today. And I understand somebody already asked the question—I was in the Education Committee and I understand that somebody already asked the question about STEM education and the workforce.

So I'm going to ask you, we were all fascinated by the recent photos of Pluto beamed backed by the New Horizons mission. It seems like we're making some incredible discoveries about distant bodies in our solar system at a regular pace, and that's really exciting for our country and our world. And although we continue to study our home planet to better understand and predict its changes, we've also learned that in some cases it's important to study Earth from a distance in order to understand its processes and mysteries. So how does what we're learning in the outer region of the solar system help us inform our understanding of Earth? Dr. Grunsfeld, would you please start?

Dr. GRUNSFELD. Well, certainly. For all of our missions, we're observing our solar system in a snapshot of time. And, you know, obviously we live on the Earth, we can go outside. When we're not in rooms with all the shades closed, we can observe the Earth and we can try and understand the geology of the Earth in great detail over past times. We can look at tree rings, we can look at glaciers, we can really try and put the picture together.

But studying how other planets evolve, and we usually have used Venus and Mars as sort of bounding cases of the direction Earth could have gone to try and understand the climates of other planets, the geology of other planets, and on Earth there's really a

unique thing, which is as soon as life emerged on Earth, it started changing the geology, the atmosphere. You know, just microbial life had a really remarkable effect on the evolution of Earth. And so looking at planets like Venus and Mars, we don't know if there was ever life on Mars or if there is today; that's what we're trying to find out. It gives us a lot of information.

There's also the question of fundamental questions. Where did we come from? How did the Earth get to be the way it is? And even studying planets like Mercury have helped us understand about the delivery of volatiles and organics. That's why, you know, it's really exciting, and I'd like to pass on if you don't mind to Alan Stern——

Ms. BONAMICI. Of course.

Dr. GRUNSFELD. —to talk about Pluto because, you know, we sort of imagine that Pluto would be a frozen, you know, somewhat dead planet and we've discovered that it still has geologic processes and is in some sense as the planet—talking planetary sciences—it's still alive and will tell us something hopefully about how the solar system was assembled.

Ms. BONAMICI. Dr. Stern?

Dr. STERN. Well, thank you very much. And I have to say when the National Academies' Decadal Survey process recommended Pluto New Horizons to the top of the queue, they pointed out two very important scientific problems that exploration of Pluto could shed light on regarding our own Earth. And let me outline those for you.

One is that the Pluto system as a binary planet is believed to have been formed through the same giant impact mechanism that the Earth/moon system was formed. In fact, Pluto is the only place that we sent a spacecraft to and the only place we know of that we can reach with a spacecraft that can shed light as a second example of a satellite formation system like shaped the earth/moon system, very, very important. And if you have a chance to review the testimony that I made, I showed off the binary and what it can teach us about that just a little bit.

Secondly, interestingly enough, Pluto is rapidly losing its atmosphere compared to most planets for a combination of reasons, one of which is that the upper atmosphere is pretty warm, and that speeds the escape. It turns out the escape process, which has a fancy name called hydrodynamic escape that Pluto is suffering from inn losing that atmosphere is precisely the mechanism that took place early in the history of the Earth when the Earth's atmosphere was made of hydrogen and helium, which are poisonous, and which led to the development of the current-day atmosphere in part.

This is not a mechanism that one can study anywhere else in the solar system on a planetary scale except at Pluto, so it's a window back in time into the early evolution of the Earth's atmosphere. And who would have thought that we had to go 3 billion miles to study fundamental aspects of the physics that have shaped our own planet? And yet we did.

Ms. BONAMICI. That's great. I'm going to try to sneak in another question real quickly.

Dr. Russell, now that Dawn has successfully proven the use of an ion propulsion engine for its planetary mission, what other potential science investigations could be enabled with this technology?

Dr. RUSSELL. Well, the advantage of ion propulsion is that, although it works slowly, it can accomplish the transport of large amounts of mass. So if you were taking some fairly large mission to Mars, for example, then it would be a very efficient way of transporting that material.

But just going back to the asteroid belt, there are a lot of other asteroids there and NASA's discovery proposal queue is just full of asteroid missions and many of them are employing or proposing to employ electric propulsion.

Ms. BONAMICI. Thank you very much.

I see my time is expired. I yield back. Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Ms. Bonamici.

The gentleman from Alabama, Mr. Palmer, is recognized.

Mr. PALMER. Thank you, Mr. Chairman.

And this is for each member of the panel. Where do you need funding? And you don't have all day. Where do you need help?

Dr. GRUNSFELD. You know, of course the Administration has made its request and, you know, it funds all of the things that we've outlined in the Congressional Justification to Fund. You know, the place that we're still lacking is in the cadence of these New Frontiers and Discovery programs. And of course, as you heard, research and analysis funding is always appreciated by the community.

Dr. STERN. I'm here representing myself and I wanted to bring up exactly the two points that Dr. Grunsfeld just did, and that Dr. Pappalardo did earlier. The research and analysis programs are crucial to understanding the data that comes back because the ones and zeros themselves have no meaning. It's only with the application of bright scientists working on those data that we can actually turn those ones and zeros into discoveries.

And then secondly, the cadence of Discovery and New Frontiers missions could be increased with the application of more funding and very much to the benefit not just of the research enterprise but I believe to the benefit of the United States and its standing in the world.

Dr. RUSSELL. And I would just like to second what Alan just said, exactly right.

Dr. PAPPALARDO. And I'll comment that the pace of Europa exploration depends on the pace of the funding. When we launch depends on the funding profile. And we can walk or we can crawl to get there.

Dr. BRAUN. Yeah, so I'll address that question as well but maybe with a slightly different angle. All of the missions that we're talking about here today and all of the missions that we would like to do in the future hinge on technology readiness. And today, there is a very effective partnership that has emerged between the Science Mission Directorate at NASA and the Space Technology Mission Directorate at NASA in creating the technologies needed for future missions.

So one of the things that I think is imperative for Congress to recognize and to recall is that without the investments in technology to enable our future missions, those future missions won't happen. And I can give you a list of four or five technology areas, some of which are actually included in the House Appropriations bill.

Mr. PALMER. As exciting as these missions are, and they are tremendously exciting—I'm from Alabama. As the Chairman mentioned, we have the Marshall Spaceflight Center. There's a lot of research going on in Huntsville and in Birmingham. As exciting as this is, though, I think one of the things that needs to be emphasized is the commercial and private sector benefit of what's being done through the space program. I mean we've had tremendous advances in the quality of life because of these programs.

How do you see these missions impacting that? Are there new technologies that you think will emerge out of this that are going to impact—that can be applied in the private sector that's going to impact quality of life? I think that's going to help sell a lot of this.

Dr. GRUNSFELD. Well, there's sort of a high ground and then there's this specific ground. On the high ground, as I mentioned earlier, when we ask our contractors, our companies to build these detectors, to build the spacecraft, the propulsion systems, the power systems, we're asking them to do things that no one has ever done before. And we push the engineers and the technicians and even the managers to do things that cause companies to be stronger.

On the other hand, once we build these things, for instance, the ChemCam instrument on the Mars Curiosity rover, those developments are quickly turned around into things that are commercialized and used here on planet Earth, whether it's to look for counterfeit drugs or new detectors for cameras that very quickly make it into cell phones, handheld devices for detecting explosives and chemical agencies, new detectors that are used in our defense industry. You know, and the list goes on. Almost every one of our scientific instruments is relatively quickly through the development cycle mapped to something that is either commercialized or has commercial benefit.

Mr. PALMER. I have one last question quickly, and that is in regard to the near-Earth objects. Is there any plans for a manned mission to any of those? My understanding is that there's some potential for a lot of benefit in terms of exploration of a near-Earth object.

Dr. GRUNSFELD. So we have a mission in the Science Mission Directorate called OSIRIS–REx, which is a robotic mission to go out to a potentially hazardous asteroid that's 500 meters across, grab some samples, and bring it back to Earth where, you know, humans will—scientists will analyze it. And also the Administration has proposed, NASA has proposed the Asteroid Redirect Mission, which is going to bring a near-Earth object into a lunar orbit where the Orion spacecraft and SLS will then deliver astronauts to interrogate the asteroid.

Mr. PALMER. I see my time is expired. I don't think that bell was acknowledging that, but thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Palmer.

The gentleman from Michigan, Mr. Moolenaar, is recognized.

Mr. MOOLENAAR. Thank you, Mr. Chairman. And I also want to thank the panel for your presentation and just answering these questions.

I want to go back. A number of people have brought up this topic of STEM education and the next generation and how, you know, planetary science can really inspire. And what strikes me—and my history may not be 100 percent accurate; you guys would know better than I do—but, you know, as I look through history, there was an issue of military competition or superiority with Sputnik where, you know, we were in a race with the Soviet Union. There was President Kennedy saying we wanted to land a man on the moon. There have been different commercial goals with space exploration.

But it seems to me in every one of those cases there was sort of these unifying goals that got, you know, NASA and the country sort of rallying behind something. And then, you know, if you watch a movie like October Sky you see how students wanted to build rockets. And it really galvanized public support and private, you know, interest as well.

If I had to ask each of you if there were three unifying goals right now when you think of space exploration, you know, I would think of things like, you know, military and defense applications, you know, commercial technologies, you know, origin-of-life questions, life beyond. Are there three that you can think of the really captivate sort of the mission that we're on today if there were kind of unifying goals that everybody would say, yes, those are the goals? Or are they all different, and that's one of the reasons it's challenging to communicate maybe the priorities for the next generation?

Dr. GRUNSFELD. Well, let me start off, and again, I'll kind of take the high plane and then we'll see where it goes, but what drives me as the head of science for NASA are really three questions. Where do we come from? You know, what is our origins? Where are we going? Where's the universe going but also where are we going here on planet Earth? And then the final one, which, you know, for me is sort of the highest priority but I don't want to pick favorites is are we alone? You know, and I think, you know, that's one where people—not everyone but any, many people on planet Earth want to know. Are we alone in the universe? And we are on the cusp of being able to answer that question technologically because the investments we're making in space technology are both on the ground and in space.

Dr. STERN. Well, I'd speak to some other threads. In terms of the science, I think that there's a vast interest in understanding our origins, which we do not only through the planetary program but through the astrophysics program, for example, as well in NASA's Science Mission Directorate. Exploration I think is a very important theme but I think people in the public really are excited by exploration, as shown two weeks ago by the exploration of Pluto and the viral response that it got. That's a very important way that we can motivate and excite people about just what we as humans can achieve.

And finally, I'd like to speak to tech careers. All of us are in tech careers as scientists or engineers or technologists, and I know I see

this a lot in speaking about New Horizons, the other missions I'm involved in. Young people are really envious of careers in the space program. And from my understanding, although space excites lots of kids to go into tech careers, about 90 percent or something in excess of 90 percent end up in other aspects of the tech economy, which I think is just fantastic, that we are the attractors to fuel the economy of the mid-21st century, and yet we don't need all those jobs to make the space program go, that it can go to fuel the internet and the biotech and other revolutions that we all want to see improve quality of life.

Dr. BRAUN. Yeah, if I could add to that for a moment, I think both John and Alan spoke to the knowledge benefits that our space program provides and that is clearly what is most relevant to the hearing today. Economic benefits are strong. Alan just alluded to some of those. But let's not leave out national security. Our ability to inspire people worldwide has international implications that are very helpful to this country.

And there are really some very significant societal benefits. It's hard to go anywhere in our society today and not be impacted by something that came from the space program whether it's the clothing that you're wearing while you're skiing or nutrients that are in about 80 percent of the baby formula that our infants in this country are taking as supplements. So, you know, those are a number of other reasons.

Dr. PAPPALARDO. If we have time, I'll speak to the "are we alone?" question just for a moment. This is really a question that drives when I go out and talk with school kids. It really inspires them, really gets them interested. And if we think about its relevance for science, we have just one example of biology on our planet. It all works kind of the same way, uses the same amino acids and uses the same storage for energy. And if we, by exploring a place like Europa or other icy moons or Mars, could find an example of a different kind of life on the outer planets' satellites, that would have to be an independent origin of life, whereas Mars there could be transfer between Earth and Mars that happened early in the solar system. It would be remarkable to see is it similar to life on Earth or is it completely different? Does it use different molecules? Does it have a different handedness of those molecules? It would really revolutionize the field of biology.

Chairman SMITH. Thank you, Mr. Moolenaar.

You all might be interested in knowing that we have a hearing scheduled in September on that subject, "are we alone?" So we will follow up. We've had hearings before; we're going to have another one in September.

The gentleman from Illinois, Mr. Hultgren, is recognized for his questions.

Mr. HULTGREN. Thank you, Chairman. Thank you all for being here. This is very important and actually exciting for us and important for us to be talking about these things, so I want to just thank you for your work. Thanks for being here today.

I do especially want our kids to know that there is a future in science because by definition these are smart kids that would be interested in this and they will make the smart choice and avoid

these fields if we are not supporting it. And so it is so important for us to support it, science and space and exploration.

Dr. Grunsfeld, you said it best in your written testimony so I'm just going to quote it again, and it doesn't get said enough that "space exploration is difficult, requiring our best and brightest engineers and scientists in order to succeed. And when we develop innovative probes to explore the solar system, we invent technologies which improve our lives here on planet Earth." I also think the same can be said about all the other "big science" projects that we're working on, be it at CERN or the North Pole or a mile underground at the Sanford Underground Research Facility trying to detect dark matter, which I had the pleasure of touring just a couple weeks ago.

But again, for me a lot of this does go back to figuring out how we can get our kids to get into these fields. NASA does a lot of great work in the STEM fields, and frankly, I wish our other research agencies have the ability to get into the classroom more easily. If I were Administrator, I'd probably be pushing for a few days' paid leave if my scientists wanted to go and help kids to build robots or visit a science class. If nothing else, we should be doing everything we can to help our scientists volunteer. They do this because they love it, not to make a buck.

I would ask each of you if maybe you could share with the Committee as we're closing up this hearing if there was a teacher or mentor or role model that convinced you that this is what you wanted to do, if you the kind of give a shout-out to that teacher or mentor. And when was it that you actually realized that this would be your path? Were you a kid? Were you in college? Were you a postdoc? And what do you think is maybe the most important time for kids to get exposure to this work?

Dr. GRUNSFELD. Sure, I'll go ahead and start. I actually—I really appreciate your comments. I have a belief that all children are born as scientists and—scientists and engineers. We crawl around and we try and figure out how does the world work? You know, in fact, we're genetically programmed to do that. And so it's up to parents, which are the largest demographic of decision-makers in our country, to make good decisions on, you know, the education of our children. And I'm just very lucky that I had two parents that were very nurturing and interested in science and nature.

But in the third grade I was asked as part of my class south side of Chicago, Hyde Park, Mrs. Loeb, first biography I ever had to write. And she started in the front row and she started just assigning people for students to write about. So there was, you know, Abraham Lincoln, George Washington, Babe Ruth, you know, and she got to me—I was in the second row—and without missing a beat she said Enrico Fermi and then just continued on down the line. And my heart just sank. I thought why didn't I get somebody famous? Well, Enrico Fermi, an American Italian physicist who helped in the Manhattan project, it turns out—and I met her years later and thanked her and gave her actually a patch that I flew on the space shuttle and met with the students and subsequently flew a patch that the students designed on another space shuttle from the south side of Chicago. But she said it was totally random.

But Enrico—I grew up on the south side where Enrico Fermi taught and so I got to meet people that he interacted with. I got to ride my bike to the first atomic pile. And I was just fascinated by it all and I credit that with, you know, becoming an astronaut and a scientist and being here to talk to you about it.

Mr. HULTGREN. That's great. Any other?

Dr. STERN. Well, if we're taking this in order, I would say that I don't remember ever wanting to do anything else in my life except be in the space business. You might say that that's a fine line between in the groove and maybe stuck in a rut. But I always wanted to do this and I always strove to be able to do it. And my parents supported me very strongly in that. I had many teachers along the way.

And what I've noticed in raising my own children is that when they're interested in science and technology, oftentimes they go through this mid-period somewhere in middle school and the early parts of high school where a lot of kids drop out of their interests in science and tech, and personally my advice has always been to follow your heart and the rest will probably work itself out.

My own mentor that I'd like to mention is a little counterintuitive, is much later in my life because I emerged from graduate school as an engineer and worked as an engineer in the space program but had a bent towards science that was recognized by my laboratory director, Dr. Charles Barth at the University of Colorado, and he kept slotting me into scientific positions, although an engineer, as project scientist for a satellite, project scientist for a sounding rocket, and he made me fall in love with science. So I went back to graduate school at age 30. And he believed in me. So it really made a difference.

Dr. RUSSELL. And just a short—

Mr. HULTGREN. Our time goes by too fast, but yeah, if you can just maybe give a quick shout-out to a teacher or mentor.

Dr. RUSSELL. Yeah, right. I had a guidance counselor who was trying to push me into engineering but I knew deep down inside I wanted to be a scientist and I didn't listen to her.

Mr. HULTGREN. Good for you.

Dr. PAPPALARDO. Tom Cramer on Long Island might be out there watching this webcast as well and inspired me in sixth grade, and as I mentioned in my testimony, Carl Sagan during my college years.

And I want to point out the issue that when I taught elementary school science lab, there was such enthusiasm and excitement among the entire class, including the girls at that level, and we lose a lot of the girls when going to the junior high and high school levels, and I think that's something we continue to need to work on.

Dr. BRAUN. If I could just quickly add, I grew up in Maryland, in Rockville, Maryland, and my father was an engineer at the physics lab where New Horizons was flown from. And that was—he certainly inspired me to—you know, in an engineering direction. But when I was 11 years old, Viking landed on Mars and I was fortunate enough to be able to go to the Goddard Spaceflight Center to witness that landing. And there was a guy on TV, you know, TV screen jumping up and down, he had long hair, he was wearing

a very colorful shirt, he was some kind of engineer and, you know, he's very proud of that moment of that first U.S. planetary lander. And I thought, boy, I want to be like him. And it turns out that guy was Gentry Lee at JPL, who I have since had the great fortune of getting to work with as a colleague. And he's still as energetic as he ever was.

Mr. HULTGREN. Well, thank you.

Chairman, thanks for your indulgence. All of you I think certainly are providing some of that same inspiration and mentorship to young people today, and so I want to thank you for that.

Quickly in closing, Dr. Rumsfeld, unfortunately—like you said, all of us are born engineers. I think I was unfortunately born a lawyer and so I think that's a curse. But I wish I had your abilities but I share in it and want to champion what you're doing.

So thank you, Chairman, and I yield back.

Chairman SMITH. Thank you, Mr. Hultgren.

Without any question, you all have made all of your mentors proud—

Mr. HULTGREN. Absolutely.

Chairman SMITH. —if you haven't surpassed them, and so that's nice to see.

And without objection, the gentlewoman from Maryland, Ms. Edwards, is recognized for an extra minute.

Ms. EDWARDS. Just a minute, I had a question, but I really actually wanted to point out—and none of you did—there was a recent news report that said the New Horizons—the New Horizons mission, there were—25 percent of the team that worked on New Horizons were women, and I think that that is something that we need to really celebrate.

My recollection when the Curiosity rover landed, there was a team of women who were the team that developed one of the major instruments there. I think that we have the potential to inspire a new generation. And when I looked at that photo on NASA.gov—everybody go to it—that team of women right there in that photo, it gives me chills.

Thank you very much, and I yield the balance of my time.

Chairman SMITH. Thank you, Ms. Edwards.

This has been a wonderful hearing. Thank you all for inspiring us, and we look forward to being in touch. And we are adjourned.

[Whereupon, at 12:02 p.m., the Committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. John Grunsfeld

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, NASA

Questions submitted by Rep. Lamar Smith, Chairman

Question 1:

When does NASA anticipate requesting funds for another flagship mission, like the Mars Rover 2020 or a Europa Clipper mission?

Answer 1:

At this time, NASA's Planetary Science Division is focusing on formulation and development of the current Mars 2020 and Europa flagship missions, maintaining our 14 operational missions, planning for future Discovery and New Frontiers missions, and conducting a healthy research and technology development portfolio. We do not anticipate requesting funds for another flagship mission until the Mars 2020 and Europa missions have completed development and the necessary funding for a flagship-class mission becomes available.

Question 2:

Traditionally, planetary exploration was a public sector endeavor, with tax-payer funded programs. Today, U.S. private sector companies are beginning to invest in and develop planetary exploration programs. What is NASA doing to facilitate and encourage private-sector planetary exploration without crowding out private sector investment?

a. How could the planetary science community benefit from private sector planetary exploration?

Answer 2 & 2a:

Private sector planetary exploration, depending on what form(s) it ultimately takes, could provide direct or ancillary benefits to the planetary science community. For example, the development of innovative, lower cost launch systems would benefit all space customers and could allow an increase in the number of planetary science missions. Alternatively, in the future, the private sector may be able to provide telecommunications services at places like Mars, allowing NASA to purchase communications services at a cost that is less than launching and deploying communications relay satellites around other planets. NASA could also potentially fly instruments on private sector missions or host private sector instruments on NASA missions, similar to how the agency works with its international partners.

Question 3:

To explore the outer planets and Kuiper belt, nuclear power sources are needed. While great advances have been made in solar power and we are now sending a solar-powered spacecraft to orbit Jupiter, there is no way around the physics the deeper we go into space the harder it is to use solar power. There is concern in the science community about the inventory of Plutonium 238, the fuel which powers long-distance robotic spacecraft and rovers. There is also concern that NASA is not investing enough to develop the next generation of nuclear power source technology. What is NASA doing to ensure we have proper inventory of fuel and the advanced technology necessary to do great exploration of the outer planets and Kuiper belt?

Answer 3:

To ensure NASA has the proper inventory of fuel for future use, the Science Mission Directorate's Planetary Science Division is currently funding the Department of Energy (DOE) to restart Plutonium 238 (Pu-238) production. Multi-gram quantities of the material are expected to be produced and delivered in 2016 for the first time under this project. The target production rate of 1.5 kg/year supports the expected mission cadence over the next two decades for competed and flagship-class missions. With regards to technology, NASA and DOE are currently working together to develop new power conversion technologies. The program is invested in Pu-238 production and high efficiency power conversion technologies - with priority research areas in Stirling technology, thermoelectric technology, and improvements in Radioisotope Thermoelectric Generators (RTG) performance. The program is also sustaining both DOE and NASA capabilities to process plutonium-238 and build, fuel, test, and fly radioisotope power systems between usage for specific flight opportunities.

Question 4:

The current National Research Council planetary science decadal survey, Visions and Voyages for Planetary Science, was published in 2011. Have there been any major breakthroughs in planetary science since 2011 which justify reconsidering any of the decadal survey recommendations?

Answer 4:

While it is not customary to reconsider the recommendations of the current decadal survey given their broad and diverse proposal of science priorities, there have been numerous breakthroughs in planetary science, most recently with the New Horizons flyby of Pluto and Dawn's arrival at Ceres, which will undoubtedly be taken into account by the National Research Council when setting the priorities for the *next* decadal survey. In addition, per Congressional direction, the NRC will also conduct a mid-term review in 2017-18 to analyze NASA's progress towards achieving the recommendations in the latest planetary science decadal survey.

Question 5:

Is an outer planets exploration program needed? What would it add that is currently lacking to NASA's plans for solar system exploration?

Answer 5:

Planetary Science currently maintains a dedicated outer planets budget, managing two NASA flagships, Cassini and Europa, and our participation in ESA's Jupiter Icy Moons Explorer (JUICE) mission. In addition, the outer planets missions compete in Discovery and New Frontiers opportunities. Outer planets research is funded through multiple research programs, and the search for life is funded through the Astrobiology Program. Needed technologies are funded though the Radioisotope Power Systems Program. Under the current Planetary budget levels, formalizing these efforts under a single Outer Planets Program would not improve mission opportunities without eliminating other existing programs. Further, putting those efforts under a new program would add a layer of complexity and reduce opportunities to compete for the best mission ideas.

Question 6:

With the scientific and public outreach success of New Horizons, is NASA prepared to request restored funding to its Planetary Science Division to enable more of these missions?

Answer 6:

NASA's science program is an integrated endeavor that recognizes and leverages the fact that the universe and all of its parts are inextricably linked. The FY16 President's request invests optimally across the full range of NASA science priorities and achieves a balance that allows NASA to realize interdisciplinary scientific goals in an effective and efficient way. The request shows a total budget for Planetary Science of $1,361.2 million for FY 2016. This budget strategy concentrates on implementing recommendations from the latest Planetary Science Decadal Survey, a process that is well supported by Congress and the science community.

To ensure top mission priorities of NASA and the planetary science community are accomplished, this budget provides the full five-year funding plan for the Mars 2020 mission, initiates formulation for a new mission to Europa, and releases the next New Frontiers Announcement of Opportunity in 2016. Additionally, the FY 2016 request continues development of InSight (Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport) for launch in March 2016 and OSIRIS-REx (Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer) for launch in September 2016; supports the production of planetary exploration enabling Plutonium-238 in partnership with the Department of Energy; provides for instrument contributions to the ESA's ESA-led cooperative BepiColombo, ExoMars and JUICE (JUpiter ICy moons Explorer) missions; and maintains support for planetary science technology and research awards.

Question 7:

After 2017 there are no planned U.S. missions to the outer planets beyond Jupiter. What specifically might be done to ensure a robust outer planets science program?

Answer 7:

We launched the latest outer planets mission, Juno, in 2011. Funded under New Frontiers, Juno is on its way to Jupiter and is scheduled to enter into orbit July 2016. Future efforts include NASA's partnership with ESA on three instruments on the ESA-led JUICE mission, which is scheduled to launch to Jupiter in 2022. NASA has also entered into formulation for a mission to Europa, one of the moons of Jupiter, which is currently planned to launch in the mid to late 2020's. Additionally, outer planet opportunities exist through the competitive Discovery and New Frontiers programs.

Question 8:

What annual budget is necessary to carry out the planetary science missions recommended by the National Academies of Sciences Decadal Survey?

Answer 8:

The National Academies of Sciences Decadal Surveys provide the scientific community's highest science priorities in a particular science theme for the subsequent ten years. Each NRC Decadal Survey committee develops funding scenarios to inform its deliberations, and these funding scenarios often exceed NASA's expected available funding levels. NASA, working with the Administration and Congress, has to develop annual budgets that balance the scientific priorities across the four main science themes, other NASA and national priorities, and the realities of a constrained fiscal environment. The President's FY16 budget request funds a balanced portfolio of science, exploration, aeronautics and technology programs, and includes a total budget for Planetary Science of $1,361.2 million for FY 2016.

The Planetary decadal survey identified ten missions to be developed during this decadal period, at a total estimated cost of $15B in FY15 dollars, including launch vehicles. This is in addition to an approximately $600M per year budget for on-going operations, management, technology, radioisotope power, and research.

Question 9:

The FY16 budget stated that NASA is moving forward with a mission to Europa, a moon of Jupiter. The House has authorized and appropriated funding to move forward and has set a goal for launch in early 2020s. However, NASA's projected budget for this mission does not seem consistent with this goal. Is NASA committed to launching a mission to Europa by the early 2020s?

Answer 9:

NASA recognizes the significance of Europa exploration and its potential to address fundamental questions related to life beyond Earth. NASA has selected the Europa flyby mission concept, and the Europa project has been approved by the Agency to enter formulation. With the President's FY16 budget request and previously appropriated funds there is sufficient budget to fully develop the requirements to support a System Requirements Review and conduct Key Decision Point B in 2016. Once the requirements are base-lined, the budget required for specific launch readiness dates will be understood, and the trade-offs between Europa launch schedule and other missions in the Planetary Science portfolio can be made.

Question 10:

A Mars sample return mission is a top priority of the planetary science community. Mars 2020 is planned to gather samples from the Martian surface and prepare them for a second mission, which would place the samples into Mars orbit, followed by a third mission slated to bring the samples back to Earth. What are NASA's plans for the second and third missions to return the samples to Earth? When might those missions occur? Could the second and third missions be combined into a single mission?

Answer 10:

NASA recognizes the scientific importance of collecting and studying samples from Mars, which is why the Science Mission Directorate is working diligently to ensure a successful Mars 2020 mission with an effective sample caching system. Viable mission architectures for sample return could include fewer (or more than) three robotic missions, and could also include crewed exploration systems as part of the sequence of sample return. There are no current missions planned to return samples, although future human missions will undoubtedly return samples. Future Mars missions beyond the Mars 2020 mission will be evaluated as part of future planning for NASA's integrated approach to the exploration of Mars.

Question 11:

With the discovery of a complex surface on Pluto, and water oceans throughout the outer solar system, is NASA ready to commit to a systematic program of outer planet exploration in the same vein as our robotic Mars Exploration Program?

Answer 11:

Please see response to Question #5, above.

Question 12:

New Horizons has been a very successful planetary science mission. It was funded as a NASA New Frontiers program mission. What are lessons learned for future New Frontiers

Program missions? And what recommendations do you have for future New Frontiers announcements of opportunities?

Answer 12:

NASA applies the experience it gains from competitive planetary mission, both in New Frontiers and Discovery, to improve the Announcements of Opportunity NASA uses to select missions. New Horizons was notable, among other things, for its detailed planning (in terms of both spacecraft operations as well as for public outreach) well in advance of the flyby with Pluto. This experience will improve advanced planning in these areas for future missions. This lesson is already being applied to the OSIRIS-REx mission (currently in development) and the Juno mission (which will reach Jupiter in mid-2016).

Question 13:

The last New Frontiers Program announcement of opportunity was in 2011. According to NASA's FY16 budget request, NASA plans on holding the next New Frontiers Program announcement of opportunity in 2016. How does FY16 funding for NASA's Planetary Science Division impact the scheduling of the New Frontiers Program? How would the cadence of new opportunities for missions be impacted by a planetary science budget of $1.5B, as authorized by this committee, as compared to the Administration requested $1.36B?

Answer 13:

As mentioned in question #6, the President's FY16 budget request releases the next New Frontiers Announcement of Opportunity in 2016, eight years after the New Frontiers 3 announcement. The future New Frontiers mission cadence would be expected to be every five-to-six years. There is a possibility to increase this cadence if additional funds were provided. .The President's request reflects careful balancing of the scientific priorities across the four main science themes, other NASA and national priorities, and the realities of a constrained fiscal environment.

Question 14:

What are the limitations of using solar power for the exploration of the Outer Solar Systems?

Answer 14:

As solar power capabilities continue to improve, select missions to the outer planets have become possible. Missions to Jupiter distances from the Sun are now possible, with the solar-powered Juno mission arriving July 4 next year, and ESA's JUICE mission and the NASA Europa mission planning to use solar power. As distance from the Sun increases, so does the size of the necessary solar panels, so solar powered missions much beyond Saturn are not likely. Additionally, missions at these distances that are not in near continuous sunlight are not currently possible using solar power. This precludes using solar power for orbiting or landing on specific moons of Jupiter or Saturn.

Question 15:

If the Space Launch System (SLS) was to be used for a science mission, should the cost of the SLS launch be divided between the science directorate and human spaceflight directorate?

Answer 15:

Currently, there are no planned science missions that require the use of SLS. At this time, SMD is actively working with Human Exploration and Operations Mission Directorate (HEOMD) to better understand the associated launch costs for potential future science missions on the SLS.

Question 16:

NASA, DOD and commercial satellites are using solar electric propulsion to ever greater extent. How can a Mars sample return or even a return of material from the Mars moon Phobos benefit from solar electric propulsion applications?

Answer 16:

As NASA seeks to reduce costs and extend the length and capabilities of ambitious new solar system science and exploration missions, alternative propulsion technologies may deliver the right mix of savings, safety and superior propulsive power to destinations beyond Earth orbit. High-power, high-efficiency Solar Electric Propulsion (SEP) systems require less propellant, typically 10 times less than a comparable, conventional chemical propulsion system. Less propellant reduces the size and cost of launching the mission into space. A future mission to Mars or one of its moons would likely be less expensive, and potentially less complicated, using SEP. NASA's Space Technology Mission Directorate (STMD) has been maturing key technologies to increase the performance of SEP systems, including solar arrays, thrusters and power processing units that will benefit a wide variety of applications. Such a mission could also be a stepping stone toward fulfilling NASA's strategy to position future habitats, landers, and other elements in Mars orbit prior to a crewed mission.

Question 17:

What is NASA's plan to provide for the return to Earth, samples cached during the Mars 2020 mission? How, if at all, will NASA be relying on international partners to collect and return Mars 2020 cached samples?

Answer 17:

As mentioned in the response to question 10, the viability and significance of specific Martian materials will be better understood once samples have been acquired and investigated by the Mars 2020 rover. Return of any particular samples is beyond the current budget horizon and is being evaluated as part of future planning for NASA's integrated approach to the exploration of Mars.

The Mars 2020 mission includes several international contributions that will enable the selection and caching of samples on the surface of Mars. In addition, NASA regularly confers with potential international partners to assess cooperation in the future exploration of Mars. Such efforts include conducting joint concept studies for missions that could contribute to returning samples from Mars. NASA expects that international partners will collaborate on future missions as their national priorities and funding availability allows.

Question 18:

Will NASA be participating in the planned October 2015 US-China Civil Space Dialogue? If so, is cooperation on planetary science and the exploration of our solar system on the agenda? If so, what is NASA's position with regards to cooperating with China on civil scientific exploration of our solar system and beyond?

Answer 18:

Yes, consistent with NASA's certification to Congress dated July 31, 2015, NASA will participate in the State Department-led U.S.-China Civil Space Cooperation Dialogue to be held on September 28, 2015, in Beijing, China. The agenda includes a briefing by each side on respective space exploration plans and programs; NASA will deliver that presentation for the U.S. In planetary science, NASA will discuss the exchange of respective lunar science mission information; that area of discussion was previously certified to Congress. The reactivation of the long-standing agreement between NASA and the Chinese Academy of Sciences for cooperation in space geodesy, and the coordination of Earth observation data products for glacier characterization in the Himalaya region, both also certified previously to Congress, will be discussed under an agenda item for Earth science. These areas of limited cooperation are intended to encourage China to implement free and open access to space and Earth science data and to make such data available to researchers worldwide through publicly available data repositories.

Question 19:

How has NASA been working with industry to further scale and develop solar electric propulsion, so the United States maintains its lead in this key technology over other countries?

Answer 19:

Over the last five years NASA, primarily through the Space Technology Mission Directorate, has engaged the domestic satellite manufacturing industry through a series of technology development and study contracts to determine how present-day and next generation commercial satellite platforms can utilize the next-generation electric propulsion systems being developed by NASA. The technology development contracts focused on very large solar arrays to reliably generate 10's of kilowatts of energy at a low mass and volume. This power capability is critical to enable high power electric propulsion systems. Through the study efforts it has been determined that commercial spacecraft with power levels up to 30 kilowatts can effectively use the NASA-developed, next-generation electric propulsion systems for orbit-insertion. Replacing conventional onboard chemical propulsion systems currently used for orbit insertion with electric

propulsion systems can increase payload mass, increase operational lifetime, or decrease spacecraft launch mass. Each of these benefits, either individually or in combination, significantly enhances the competitiveness of United States commercial spacecraft in the global satellite market.

Question 20:

What improvements are needed to the solar electric propulsion in use today, on for instance the USAF's Advanced EHF satellite, to ensure that we have the solar electric propulsion capabilities needed for a 2020s demo mission and for a 2030s Mars mission?

Answer 20:

The power levels of present-day systems are not sufficient for time-constrained delivery of payload masses in excess of 5,000 kg. Improvements are in development to increase the size, power level, and thrust produced by electric propulsion systems to support a 2020 demonstration mission and to support follow-on missions to Mars. By implementing these improvements in electric propulsion systems, next generation spacecraft can utilize propulsion systems with a fuel economy as much as ten times greater than existing chemical systems for orbit transfer applications. NASA's Space Technology Mission Directorate (STMD) took a very important step recently on this future path by soliciting a 12.5 kW electric propulsion thruster system from industry. In addition, STMD recently completed a development effort of two solar array designs that will reduce mass and allow for more efficient packaging, which will allow for increased power while keeping the mass down. STMD is aiming to demonstrate a 40kW Solar Electric Propulsion system as part of the Asteroid Redirect Mission. This system will be extensible to Mars cargo missions and will include power enhancements that will feed forward to deep-space habitats and transit vehicles.

Question 21:

NASA's Planetary Science Division has a technology program independent of the Science Technology Mission Directorate (STMD). What technology research and development is conducted within the Planetary Science Division and how is it different from STMD technology development?

Answer 21:

The Planetary Science Division (PSD) maintains investments in technology priorities that specifically meet its mission's requirements for new capabilities. These investments are typically mid-Technology Readiness Level (TRL) technologies that require further maturity towards a flight development decision, or TRL 5-6 technologies that are demonstrated ready for flight development. PSD develops these required technologies into flight systems. These investment priorities are defined objectively through mission studies, and informed by the Decadal Survey and through regular engagement with the planetary science community.

The Space Technology Mission Directorate focuses on enabling or broadly applicable technologies with infusion into potential future missions, and typically does not develop technologies beyond the TRL 6-7 flight demonstration phase. STMD develops its technology portfolio through input from the Agency's Space Technology Roadmaps and subsequent NRC recommendations, the Agency's Space Technology Implementation Plan, and stakeholder input from Mission Directorates.

PSD and STMD coordinate investment strategies to ensure that efforts are complementary but not overlapping. In areas that are applicable to only Planetary Science, such as radioisotope power conversion technology, Planetary Science typically takes the lead for the Agency. In areas with broader applicability beyond just Planetary science, such as Solar Electric Propulsion, improvements in space-based computer performance and Entry, Descent and Landing technologies, STMD typically takes the lead for the Agency.

Question 22:

What research, if any, is NASA undertaking relevant to the terraforming of Mars?

Answer 22:

At this time, NASA is not undertaking any research relevant to terraforming Mars.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, NASA

Questions submitted by Rep. Donna Edwards, Ranking Member, Space Subcommittee, Committee on Science, Space, and Technology

Question 1:

What is the status of NASA's work with the Department of Energy to restart production of the plutonium 238 material that is used for developing radioisotope power sources? When will production begin, what is the estimated amount of material that will be produced each year, and what are the primary mission needs for the material?

Answer 1:

SMD's Planetary Science Division is currently funding DOE to restart Pu-238 production and multi-gram quantities of the material are expected to be produced and delivered in 2016 for the first time under this project. The target production rate of 1.5 kg/year supports the expected mission cadence over the next two decades for competed and flagship-class missions. The Pu-238 supply project budget is $15M in FY2016.

NASA is working with DOE to ensure our needs for plutonium-238 will be met in a timely manner. DOE has informed NASA that 35 kg of Pu-238 has been allocated out of its stockpile for civil space use, and of this material, 17 kg is currently in flight specification. Additional material can be brought into flight specification by blending new or currently-in-spec material with the out-of-spec material. This allocation should meet NASA's requirements for the next 15 years. If domestic production of Pu-238 should be delayed or interrupted this could result in less power performance and/or delays in RPS mission opportunities. NASA will work with DOE to minimize any power impact or delay to mission plans.

Question 1a:

What do you estimate the annual cost will be?

Answer 1a:

Please see response to Question #1, above.

Question 1b:

What contingencies does NASA have should domestic production of Pu238 become delayed or interrupted in the future?

Answer 1b:

Please see response to Question #1, above.

Question 2:

NASA discontinued its development of a Stirling flight unit. Does NASA have any plans to restart work on a flight unit? What level of investment is needed to bring this technology to a flight ready status?

Answer 2:

At this time, NASA does not have any plans to restart work on an ASRG flight unit. NASA and DOE are currently working together to mature efficient and reliable new power conversion technologies, including Stirling power conversion. NASA RPS flight cadence is such that a Stirling flight unit is not required for the next decade. This affords NASA the opportunity to further mature the technology and demonstrate reliability before initiating a flight system development.

Question 3:

NASA's planetary science missions are identifying an increasing number of potential solar system targets at which future planetary missions might seek to detect and study past or present microbial life. With that in mind, to what extent is NASA taking extra measures to ensure that spacecraft don't bring hitchhiker microbes from Earth that could interfere with the search for microbial life on another solar system body?

Answer 3:

NASA has maintained a Planetary Protection Policy since the 1960s specifically to ensure that planetary missions do not introduce Earth contaminants that could interfere with the search for life elsewhere. Planetary protection requirements for each planetary mission are carefully tailored to ensure that the measures taken are appropriate to protect the target body, without applying excessively stringent restrictions.

Question 3a:

Have procedures to clean and check spacecraft for hitchhiker microbes changed over time? If so, in what ways?

Answer 3a:

Procedures to clean spacecraft, (i.e., physical removal of contaminants that are unwanted) depend on the specific materials used in spacecraft construction. As new materials are

brought into use, cleaning approaches are developed to accommodate them, but most of these continue to involve contact with spacecraft surfaces. New procedures, such as treatment with Vapor-Phase Hydrogen Peroxide have been accepted as methods to reduce the number of viable microbes on spacecraft hardware surfaces, but the best-understood method for reducing spacecraft-associated microbial populations remains treatment with heat.

Biomedical research has developed a number of new approaches that can be applied to characterizing the numbers and types of microbes carried on spacecraft using molecular biology '-omics' techniques. Techniques that measure specific biochemicals (e.g., adenosine triphosphate; bacterial wall components) can provide an estimate of 'pass' vs. 'fail' in the context of meeting NASA requirements; however, just as for water quality and food safety, the well-established (and less expensive) techniques of bacterial cell culture remain the standard that is most often used in monitoring process controls on spacecraft assembly.

Question 3b:

What is the current budget for research and development in planetary protection methods and what are NASA's plans for enhancing planetary protection?

Answer 3b:

NASA's investments in planetary protection are divided between mission development and implementation budgets and the budget of the Planetary Protection Officer (PPO), who is responsible as the designee of the SMD AA for maintaining planetary protection policy and requirements and monitoring mission compliance. In FY16, the budget of the PPO was $2.8M, which covers all staff support and monitoring/oversight activities, as well as approximately $1.5M in planetary protection research investments solicited through the peer-reviewed program Research Opportunities in Space and Earth Sciences.

Development of technologies that support mission implementation strategies that will be monitored by the PPO is not funded by the PPO. Office staff work with mission developers (e.g., in PSD, HEO, STMD) to identify strategic knowledge gaps where planetary protection is relevant, but decisions to fund areas with gaps are taken by the relevant implementing organization.

Question 4:

How does the future availability of the SLS affect the potential opportunities for scientific exploration of our solar system? What are the primary benefits that SLS would provide for planetary missions?

Answer 4:

Currently, there are no planned science missions that require the use of SLS. However, future use of the SLS for science missions could potentially enable faster trips for spacecraft traveling to the outer planets. Such benefits would have to be weighed against increased costs, risks, and other factors.

Question 5:

Your outreach on NASA space science missions can inform our work on the Committee. As you speak to public audiences and at schools about the discoveries planetary science missions are making, are there recurring themes in the questions that are asked? What, in your view, do school children and the public most want to know about these missions and their scientific findings?

Answer 5:

In speaking to public audiences, Mars draws significant interest among space science topics due to the familiarity and fascination with rovers, the beauty of the high-res orbital images, the possibility of human exploration, and learning about historical sci-fi references. In terms of science themes, the possibility of life on another planet and what makes a planet habitable are key themes that capture attention. A variety of rover-centered questions often revolve around engineering feats (e.g. what a rover can do, how fast it goes, how it faces and overcomes challenges etc.). Mars as an extreme planet (how it is similar to, and different from, Earth) is also a draw, a theme that extends to human survival should people travel to Mars one day. Public audiences also express an interest in Mars as a possible "second home" in case we "ruin Earth." Beyond Mars-related science, the possibility of intelligent life in the universe is always a popular theme.

For school audiences, these interest areas are similar, but topics are often tailored to what students are studying (e.g., subtopics might include Earth-science related topics such as volcanism, rock types and cycles, etc.) so questions tend to become more focused beyond initial orientation to Mars, Mars missions, and discoveries. Through evaluation, student engagement is shown to be typically high given the authentic work they do in making their own discoveries or in designing their own solutions. For example, students conduct their own research using orbital cameras and data in nationally recognized projects such as the Mars Student Imaging Project (recognized by Science magazine as a top science-inquiry project). Students engage in engineering, arts, and design thinking through multiple robotics projects in which they design and build their own robots, and Imagine Mars, a project in which students design a survivable human settlement that takes into account Mars' extreme conditions. Student programs in cooperation with science centers have also focused on remote sensing and robotics, with students taking on authentic, simulated mission roles. Themes of interest in all of these educational projects relate closely to the students' self-selected research questions to be answered or engineering problems to be solved.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, NASA

Questions submitted by Rep. Daniel Lipinski, Member, Committee on Science, Space, and Technology

Question 1:

A number of our planetary science and astrophysics community leaders, like yourself, gained critical professional development experience through testing scientific experiments on more easily accessible high-altitude and suborbital platforms. As the head of NASA's Science Mission Directorate, how do you plan to utilize commercial reusable suborbital and high-altitude platforms to develop the next generation of great planetary scientists and astrophysicists?

Answer 1:

The Science Mission Directorate (SMD) is supportive of all suborbital platforms that allow compelling science investigation and workforce development to be accomplished. The annual Research Opportunities in Space and Earth Sciences (ROSES) solicitation includes calls for proposals across all of SMD's science disciplines, and it explicitly calls for proposals that take advantage of commercial reusable suborbital and high-altitude platforms to conduct such investigations (see. E.g., ROSES-15, Section V(iii)). In addition to investigations using commercial reusable suborbital and high-altitude platforms, ROSES also solicits proposals using scientific balloons, traditional sounding rockets, and NASA-operated aircraft as platforms for science investigation and workforce development. All proposals are subjected to competitive peer review and, due to constrained budgets, only the most compelling are selected.

Balloon-borne investigations provide fast, comparatively lower cost access to near space for substantive scientific investigations and flight-testing of new technologies in space-like conditions. These programs also provide a training ground for the principal investigators of tomorrow's major missions. To date, NASA's Astrophysics, Heliophysics, and Planetary Science divisions have utilized balloon-borne investigations to address their science requirements. It is possible that other proven balloon-borne payloads may be modified for use on the International Space Station (ISS). Any such investigation would be selected only after a proposal is submitted to peer review and technical evaluation for both the scientific merit and the programmatic feasibility of the associated proposal budget, schedule, and organizational qualifications.

Lastly, SMD plans to continue to offer commercial reusable suborbital platforms as part of all our solicitations where that class of platform is in scope with the goals of the solicitation. For instance, SMD offers commercial reusable suborbital platforms as part of the University Student Instrument Project-2015 (USIP) solicitation to provide undergraduate student teams an opportunity to fly a science and/or technology payload relevant to NASA strategic goals on a sounding rocket, balloon, aircraft, or commercial suborbital reusable launch vehicle (sRLV).

Responses by Dr. Alan Stern

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Alan Stern, Principal Investigator, New Horizons Mission, Southwest Research Institute

Questions submitted by Rep. Lamar Smith, Chairman

1. New Horizons has been a very successful planetary science mission. It was funded as a NASA New Frontiers program mission. What are lessons learned for future New Frontiers Program missions? And what recommendations do you have for future New Frontiers announcements of opportunities?

    The lessons learned from New Horizons are in my view that the public is very attached to space exploration. I recommend that the New Frontier program be broadened to include missions to more unexplored locations.

2. New Horizons has left Pluto, but it still has the opportunity to explore the Kuiper Belt. What scientific discoveries might be made by New Horizons in the Kuiper Belt?

    New Horizons can make many kinds of discoveries by exploring further in the Kuiper Belt. Most notably, we hope to help understand the way in which small planets like Pluto were made by exploring smaller Kuiper Belt Objects which were the building blocks of these worlds.

3. A mountain of water ice has been discovered on Pluto How does this finding impact future mission to other planetary bodies?

    The discovery of water-ice mountains on Pluto teaches us that Pluto's surface volatiles are likely to be continually renewed by internal activity within the planet. It may be telling us that other small planets have similar activity.

4. Based on the scientific data collected by New Horizons, Pluto may be geologically active. How does this finding impact scientific understanding of our solar system and our planet?

    The finding that Pluto appears to be geologically active tells us that we do not yet understand the sources of long-lived energy in small planets.

5. What are the limitations of using solar power for the exploration of the Outer Solar Systems?

    Solar power has now been developed sufficiently that it can be used to explore within the Jupiter system and perhaps farther out to distances at Saturn and even Uranus, but to my knowledge nuclear power as used on New Horizons and Voyager is required

for any missions farther, as well as ambitious missions that require significant power at Saturn and Uranus.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Alan Stern, Principal Investigator, New Horizons Mission, Southwest Research Institute

Questions submitted by Rep. Donna Edwards, Ranking Member, Space Subcommittee, Committee on Science, Space, and Technology

1. In the days following the New Horizons flyby you said one of the most surprising discoveries the mission made was the relative lack of craters on the surface of Pluto, indicating recent geologic activity without the existence of tidal forces. Have you been able to narrow down the options for the energy source for this activity with the data that has been coming in since the flyby?

   We have not yet been able to narrow the energy sources of activity that are causing Pluto to show a lack of craters on its surface.

2. New Horizons was a competitively selected mission under the New Frontiers mission line. As the principal investigator of New Horizons, you are responsible for meeting cost, schedule, and mission performance objectives, and for the overall success of the project. How important are principal-investigator-led missions to NASA's planetary science program and how are these types of missions different from NASA-led missions?
   a. What are the challenges and benefits of this approach to space science missions?
   b. Are there any changes you would recommend?

   PI-led missions are extremely important to NASA's planetary science program, they are different from NASA-led missions in that they represent missions in which a sole individual is held accountable for their ultimate success. The challenges of this approach lie in selecting strong leaders. The benefits of this approach are that they often yield important results for a fraction of the cost of other missions types.

3. How does the future availability of the Space Launch System (SLS) affect the potential opportunities for scientific exploration of our solar system? What are the primary benefits that SLS would provide for planetary missions?

   SLS offers to enable many missions otherwise impossible owing to its high performance, allowing missions that require much more mass to orbit, land, and return samples from locations around the solar system. I cannot recommend any changes to this system because I am not sufficiently knowledgeable about it; I do however caution that it must yield not just high performance, but also high performance at affordable costs.

4. Your outreach on New Horizons can inform our work on the Committee. As you speak to public audiences and at schools about the discoveries planetary science missions are making, are there recurring themes in the questions that are asked? What, in your view, do school children and the public most want to know about these missions and their scientific findings?

   The recurring themes I am asked about by public audiences typically center on why NASA doesn't do more missions like New Horizons. School children typically ask about whether Pluto will be considered a planet by scientists in the future; I tell them yes.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Alan Stern, Principal Investigator, New Horizons Mission, Southwest Research Institute

Questions submitted by Rep. Elizabeth Esty, Member, Committee on Science, Space, and Technology

1. New Horizon's Pluto flyby earlier this month returned stunning, breathtaking images and priceless data of the dwarf planet that will inform scientific discoveries for decades to come, and I look forward to NASA and its partners continuing their groundbreaking work. With this successful mission, NASA has inspired another generation of scientists, explorers, and innovators in Connecticut and around the world. Dr. Stern, congratulations on a very successful mission to Pluto. Because so much of the data New Horizons collected has not yet been transmitted to us, it could take years to fully understand the gravity of this flyby. However, knowing what you know now, what lessons can the New Horizons mission teach us for future missions to other planets in our solar system and beyond?

    The New Horizons mission teaches that the public is highly interested in missions of exploration and that missions to new places in space inspire people about science, technology, and the historic nature of space exploration that the US leads.

Responses by Dr. Christopher Russell

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Christopher Russell, Principal Investigator, Dawn Mission; Professor of Geophysics and Planetary Physics, University of California Los Angeles

Questions submitted by Rep. Lamar Smith, Chairman

1. Traditionally, planetary exploration was a public sector endeavor, with tax-payer funded programs. Today U.S. private sector companies are beginning to invest in and develop planetary exploration programs.

   a. How has Dawn's mission improved our understanding of the economic value of asteroids?

Ans. On asteroids, we must judge economics principally in terms of potential for mineral resources. Many of the valuable minerals on Earth were created in a wet environment where materials could dissolve and later be deposited. While asteroids are usually not expected to be wet, one of Dawn's targets, Ceres, appears to have ample supplies of water and that water appears to have produced deposits of material on the surface of Ceres. When we have unambiguously determined the nature of these deposits we will be able to assess its value. On Vesta, we have found evidence for less water than on Ceres. Vesta itself did melt, so iron deposits are possible inside Vesta.

2. When the public thinks about exploration, they may not think about asteroids as important scientific targets. How does the scientific exploration of asteroids improve our understanding of the solar system and Universe?

Ans. Both of Dawn's targets, Vesta and Ceres are representative of the type of bodies that were present in the early solar system and came together to form the Earth and the other planets. So our studies of Vesta and Ceres enable us to determine what the starting materials were for the building of Earth (and Mercury, Venus and Mars). In particular, Vesta has an iron core and we believe the Earth's iron core may have begun in the interiors of many ancient Vesta-sized bodies. The water on Earth may have come from many Ceres-like bodies. Perhaps the most important result of our measurements at Vesta was to confirm that the model of the formation of the solar system based on meteorites, that had reached Earth from Vesta correctly predicted what we found at Vesta. This validation has confirmed our standard model of solar system formation.

3. In your testimony, Dr. Russell, you describe a mountain of what may be ice observed on Ceres, similar to terrestrial "pingos" found in Alaska. You mention that New Horizons detected similar mountains on Pluto. What is the relevance of finding these similar phenomena on both Ceres and Pluto? Do we think these might be common features to be found throughout our solar system?

Ans. The "pingo" example tells us how important it is to do comparative planetary studies. If we study a process in only one setting we do not learn how the process can take place in a different environment. From studying "pingos" in Alaska where the force of gravity is the same as elsewhere on Earth, some felt that "pingos" could grow only to a few hundred feet in elevation, but on Ceres and Pluto we have ice mountains that are three miles high. We do not know for certain that the ice mountains were formed the same way as Alaskan 'pingos" but it has made us question our earlier theories about what freezing ground water can do. And yes, we do believe that "pingos" may be a general feature found on many solid "icy" bodies in the solar system.

4. In your testimony, you reported that Ceres is an object of interest to the biological community – that it has water and heat sources – and might sustain life. How should this information influence the development of future missions?

Ans. The next step in understanding Ceres, and especially its habitability, is to land and directly sample the surface and its thin atmosphere. Dawn's images should be able to identify the most suitable landing sites.

5. As the principal investigator of a NASA Discovery-class mission, what recommendations, if any, do you have to improve the selection, administration, and funding of Discovery-class missions?

Ans. The Discovery program was initiated over two decades ago and has produced close to a dozen successful planetary missions. The NASA Discovery mission process works very well. The selection criteria are well laid out. The objectives of the program are clear.

The planetary community depends on this program to fill in critical gaps in our knowledge of planetary bodies. However, it has not been used often enough. When budgetary shortfalls occur in the planetary science program, the Discovery program is sometimes used to absorb the shortfall by delaying the next selection. Because small missions like those flown in the Discovery program can be developed quickly and with least risk they assure the continuity of good science return from our planetary science program. I recommend maintaining a regular annual Discovery solicitation.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Christopher Russell, Principal Investigator, Dawn Mission; Professor of Geophysics and Planetary Physics, University of California Los Angeles

Questions submitted by Rep. Donna Edwards, Ranking Member, Space Subcommittee, Committee on Science, Space, and Technology

1. Dawn was a competitively selected mission under the Discovery mission line. As the principal investigator of Dawn, you are responsible for meeting cost, schedule and mission performance objectives, and for the overall success of the project. How important are principal-investigator-led missions to NASA's planetary science program and how are these types of missions different from NASA-led missions?

   a. What are the challenges and benefits of this approach to space science missions?

   b. Are there any changes you would recommend?

Ans. I have participated in one way or another in NASA's space program for over a half century. I watched the development that led up to the establishment of the Discovery Program. The problem with what we now call flagship missions is that in order to rise to the top, the mission has to contribute to many objectives in order to win the "votes" with the community needed to allow it to go forward. The Discovery missions may address a more limited objective in competition with other limited-objective missions. This allows inexpensive, high-payoff, but narrowly focused, missions to be executed. These missions are often partnerships between Universities, Industry and NASA Centers, rather than a project that is managed totally by a NASA Center. The challenge is to work within the proposed budget, and the benefit is that (with Discovery-class-missions) it is possible to minimize cost-growth. I do believe that the process has improved over the years and is now very effective. The pace of missions has slowed because of the limited available budget. I would recommend adding a little bit more to this highly effective program to be able to address more of the small, doable objectives.

2. Now that Dawn has successfully proven the use of an ion propulsion engine for its planetary mission, what other potential science investigations could be enabled with this technology? Would this technology be capable of enabling a tour of multiple bodies in the solar system?

Ans. The ion propulsion engine is useful for transporting large amounts of mass long distances when time is not a factor. For Dawn, we did not have to rush to get to Vesta and Ceres. We just had to reach them within our budget. There are many exciting targets in the asteroid belt that could be reached with solar power. We should visit a few more of them. We also could take supplies to Mars for a Landed Mars mission or to Ceres for

a landed Ceres mission. Multiple asteroid rendezvous is possible with a Dawn class mission of course (Dawn did two) and more than two is possible. Dawn could have reached these had its reaction wheels been sturdier.

3. How does the future availability of the Space Launch System (SLS) affect the potential opportunities for scientific exploration of our solar system? What are the primary benefits that SLS would provide for planetary missions?

Ans. The SLS is the exact opposite of ion propulsion. It is the rocket of choice if you are in a hurry. Manned flights need speed but so do some unmanned missions. Missions to Jupiter, Saturn, Uranus and Neptune could be done in reasonable time periods (an unreasonable period being the length of a scientist's career). These missions are critical next explorations (especially Uranus and Neptune that have never been orbited or had a probe dropped into their atmospheres). I am very much hoping to see SLS in the mix of launch vehicles because of its rapid access to distant planets.

4. Your outreach on Dawn can inform our work on the Committee. As you speak to public audiences and at schools about the discoveries planetary science missions are making, are there recurring themes in the questions that are asked? What in your view, do school children and the public most want to know about these missions and their scientific findings?

Ans. Our planetary exploration opens up new vistas. There are surprises on the different planets. Sometimes a familiar process on Earth gives a very different result under the conditions on another planet. Possibly the large mountain on Ceres would have been a small hill on Earth with its stronger gravity. This difference makes students think. Then they get deeper understanding of this environment and the world(s) around them.

5. As a university professor, you have the opportunity to work with students on space science and technology. As you know, these talented students have choices, whether in information technology or other technical fields that don't involve space. Are NASA and the space program attracting enough of these talented individuals to feed a pipeline of experience? Or do we still run the risk of gaps in experience and expertise once senior leaders in the field retire? If so, what should be done to address such gaps?

Ans. An education in science is hardly ever wasted. The challenge is directing people with the right set of talents into the best jobs for them. Publicizing the results of our missions often allows these individuals to self-select into the most appropriate careers. Avoiding gaps in the ranks of the well-trained cadre of a technical work force requires

not fits and starts and special programs but rather a recognition that a modest steady of scientific exploration at the frontiers of our knowledge will spark the interest of the nation's most talented individuals and keep the nation at the forefront of space exploration.

Responses by Dr. Robert Pappalardo

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Robert Pappalardo, Study Scientist, Europa Mission Concept, Jet Propulsion Laboratory, NASA

Questions submitted by Rep. Lamar Smith, Chairman

QUESTION 1:

The current Europa mission concept is for a fly-by clipper, not a Europa lander or subsurface exploration vehicle. What science could be achieved by a lander or subsurface exploration vehicle that couldn't be achieved by a fly-by clipper and how much would that cost?

ANSWER 1:

The current Europa multiple-flyby ("clipper") mission concept can do an outstanding job of understanding Europa's potential habitability, through investigations of the satellite's ice shell, ocean, geology, and composition. Some of the science instruments will perform remote sensing, while others will perform in situ investigations of the satellite's thin atmosphere and potential plumes. The remote sensing instruments will be able to see materials that are exposed on the surface of Europa, where they have been processed to various degrees by radiation (i.e., by high-energy particles that hit Europa's surface). The in situ instruments will measure ice, dust, and plasma particles that have been knocked off of Europa, and these processed materials are indicative of the purer material that sits on and just beneath Europa's surface. Complex organic materials can be measured this way, but they will experience some degree of processing by radiation and by the speed of the spacecraft upon sampling in situ.

A lander would have the advantage of sampling Europa's surface materials much more directly—without the processing that occurs from surface exposure to radiation or through being knocked off of the surface and sampled at high velocity in Europa's thin atmosphere. However, the design of a lander mission (i.e., exactly where and how it should land and sample) would greatly benefit from the precursor reconnaissance that a multiple-flyby mission would provide. In addition, a lander may be significantly more expensive and complex than the currently planned Europa mission; any additional advantages would have to be weighed against potential additional costs and risks.

JPL is currently studying options on how to land on Europa. These studies are not yet complete.

QUESTION 1a:

What are we likely to discover with a clipper?

ANSWER 1a:

The multiple flyby ("clipper") concept will be able to: confirm the existence of an ocean, while measuring its thickness and salinity; find water within and beneath the ice shell and find pathways for surface-ocean-atmosphere exchange of materials; measure the composition and abundance of surface materials including simple organics; map in three-dimensions the distribution of geological features on the surface near-globally; image and map the abundance of surface hazards at the meter scale, to understand small-scale geological processes; measure the gravitational and magnetic fields in the vicinity of Europa to understand its interior and how Europa interacts with the neighboring space environments; and search for

and characterize plumes if they exist at the satellite. In this way, the mission will globally characterize Europa and make great advances in understanding its potential to support life.

QUESTION 2:

Both radioisotope thermoelectric generator (RTG) and solar photovoltaic cells are possible power sources for the Europa mission. Even though Jupiter is in the Outer Solar System, NASA decided that solar photovoltaic is the presumptive power source. Why isn't nuclear an option?

ANSWER 2:

The Europa Multi-Flyby mission team did a detailed study of the use of RTG vs. solar photovoltaic. On almost all aspects of this evaluation, solar cells were deemed the superior option for this mission concept. There are some mission designs for which RTGs are preferable; however the current mission concept allows the recharging of our batteries between flybys of Europa. Advantages include slower power degradation rates, smaller increments of changes to the power system to either increase output or decrease output to save mass, simpler integration strategies and significantly lower cost. Of all the areas we looked at, only the total mass of the power system was an area where RTGs had an advantage. The Project, with NASA concurrence, deemed the benefits of solar far outweighed the mass detriment.

QUESTION 2a:

What science could be accomplished with nuclear power that wouldn't be accomplished by solar?

ANSWER 2a:

For the current mission design of the Multi-Flyby mission, the baseline science can be achieved with solar power. There is no science proposed by the selected instruments that requires the use of nuclear power; instead, solar cells are a significant advantage.

QUESTION 2b:

What are the limitations of using solar power for the exploration of the Outer Solar Systems?

ANSWER 2b:

Use of solar as a power source for deep space missions are a problem in two situations. First, when the missions are so far away from the sun, the low solar intensity, coupled with the low temperature reduces the power generated by solar arrays. The second source of problems arises when a mission has an energy demand that is significant in both quantity and timing (as a function of the time that the mission can point the solar cells toward the sun). An example: at Jupiter distances from the sun the size of the solar arrays for a spacecraft of the power demands of the Europa multi-flyby mission are at the limits of reasonable size using current solar cell technology. At greater distances, missions would need to have significantly smaller power draw or improved (more efficient and/or larger) solar arrays to be viable.

QUESTION 3:

How will NASA's Juno mission inform the planned Europa exploration mission?

ANSWER 3:

There are two areas where Juno might provide information for the Europa mission. The first is validation of solar cell performance. We have been looking at performance of the Juno solar arrays since launch, and all of the predictions have been right on target relative to our performance expectations. We will continue to monitor this. The second area might be to validate some of our assumptions about the radiation environment. Unfortunately, Juno does not carry radiation monitors (the Europa mission will). Hence any information we gain will be inferring the environment from engineering subsystem and science instrument performance (degradation on camera images, upset rates on the electronics, etc.). While this is not very detailed information, it might be useful.

QUESTION 4:

What key technologies are being developed for the study and characterization of the surface and subsurface of Europa?

ANSWER 4:

There are three areas where technology developments are being looked at for potential use on future missions to the outer planets and their moons. The first is precision landing algorithms and hardware enabling pinpoint access to areas of interest of the scientists, informed by the reconnaissance data returned from a multi-flyby mission. The second area is in the development of high-energy capacity primary batteries to enable approximately two-week lifetimes on surfaces. The last area is the maturation of science instruments and sample delivery devices, which could operate in harsh environments such as the surface of Europa.

QUESTION 5:

What is the cost-estimate for the Europa mission?

ANSWER 5:

Given that the mission baseline has not been set through the confirmation process and the launch date has not been set, it is difficult to provide reliable cost estimates for the overall mission at this time.

QUESTION 6:

How can Congress measure whether or not a mission to Europa is a success?

ANSWER 6:

Standard NASA practice is to develop a set of formal Mission Success Criteria against which mission success can be judged. A preliminary set of such criteria were developed in order for the mission to move into the formulation phase. Those primary criteria are the following.

- Confirm or disprove the presence of a Europa ocean, and determine the nature of any surface-ice-ocean exchange.
- Identify the composition and chemistry of key salts and other non-ice constituents at Europa, and characterize any carbon-containing compounds.
- Produce ≤1-km spatial resolution-scale maps for ≥50% of Europa's surface, and measure visible surface reflectance of major landform types at higher resolution.
- Acquire data to characterize the surface properties at ~1-m scales.

QUESTION 6a:

Do you believe the potential benefits from a mission to Europa are likely to outweigh the costs of the mission?

ANSWER 6a:

More important than personal belief is the opinion of the greater scientific community, which believed that the originally scoped Europa mission, known as the Jupiter Europa Orbiter and estimated to be $4.7 billion, was unaffordable and should be flown only if NASA could reduce the mission's costs. NASA's Europa Multiple Flyby mission is expected to cost less than the Jupiter Europa Orbiter and is viewed by the scientific community as having good value for the cost. Such an opinion has been as expressed by the NASA-chartered Outer Planets Assessment Group (OPAG) and by the Committee on Astrobiology and Planetary Science (CAPS) of the National Academies.

QUESTION 6b:

What is the biggest challenge to a successful Europa mission?

ANSWER 6b:

Challenges include uncertainty in the funding profile and pressure from external stakeholders to include new mission requirements and scope, which likely would increase overall costs and potentially slow the development of the mission.

QUESTION 7:

In making budgetary decisions, how should Congress and NASA prioritize a mission to Europa?

ANSWER 7:

The 2011 Planetary Science Decadal Survey ranked a Europa mission as the second highest-priority flagship mission and warned against an overly costly mission that would "lead to an unacceptable programmatic imbalance, eliminating too many other important missions." Consistent with this recommendation, NASA supports funding a Europa mission in a sustainable and responsible manner that does not disrupt the balance of the Planetary Science Division.

QUESTION 8:

Is NASA purposefully designing exploration spacecraft, like the Europa Clipper, to avoid using Pu-238 due to supply concerns?

ANSWER 8:

No, the Europa mission selected solar arrays as the best technical solution, and not because of a concern over Pu-238 availability. Please see response to question # 2, above.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Dr. Robert Pappalardo, Study Scientist, Europa Mission Concept, Jet Propulsion Laboratory, NASA

Questions submitted by Rep. Donna Edwards, Ranking Member, Space Subcommittee, Committee on Science, Space, and Technology

QUESTION 1:

With a Europa mission anticipated for launch in the 2020s, how can relevant information obtained from preceding or ongoing missions as well anticipated technological advances be incorporated into a Europa mission plan?

ANSWER 1:

NASA maintains a detailed database of lessons learned as well as significant information transfer and heritage among our flight missions. Sharing and growing our technologies capable of surviving the unique mission environments our spacecraft endure as well as operations strategies, are essential to our continued success. Our current system architecture leverages components from many recent missions (the Mars Science Laboratory as an example). We continue to stay abreast of the most recent developments within NASA as well as the rest of the aerospace community.

QUESTION 2:

Because Europa is considered a target that could host microbial life, what planetary protection measures does the mission need to take, and what steps are being taken to plan the mission with planetary protection in mind?

ANSWER 2:

The Europa mission is very sensitive to the concerns of planetary protection. The current requirement for our mission is to assure there is no more than 1×10^{-4} chance of a spore from Earth getting to the water below Europa's vast icy shell. We are planning on meeting this requirement with a rigorous pre-assembly sterilization program, along with analysis with review and approval by the NASA planetary protection officer of the robustness of our spacecraft prior to each flyby. This latter step is similar to the current approach taken by the Cassini mission prior to each flyby of Enceladus, another outer planet moon postulated to have the potential to harbor life.

QUESTION 3:

How does the future availability of the Space Launch System (SLS) affect the potential opportunities for scientific exploration of our solar system? What are the primary benefits that SLS would provide for planetary missions?

ANSWER 3:

Currently, there are no planned science missions that require the use of SLS. However, future use of the SLS for science missions could potentially enable faster trips for spacecraft traveling to the outer planets. Such benefits would have to be weighed against increased costs, risks, and other factors.

QUESTION 4:

Your outreach on a Europa mission can inform our work on the Committee. As you speak to public audiences and at schools about the discoveries planetary science missions are making, are there recurring themes in the questions that are asked? What, in your view, do school children and the public want to know about these missions and their scientific findings?

ANSWER 4:

Outreach talks to school groups and the general public about planetary science in general and Europa in particular result in general fascination with the topic. There are indeed recurring themes in the questions asked, including:

- What would life look like there?
- What would it mean to find life there?
- Can people go there?
- How does exploring the solar system help us to solve problems here at home?

These kinds of questions demonstrate the great interest in understanding the potential for life beyond Earth and in personalizing the experience of exploration beyond the confines of their earthly experience.

Responses by Dr. Robert Braun

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Questions for the record, Dr. Robert Braun, David and Andrew Lewis Professor of Space Technology, Georgia Institute of Technology

Questions submitted by Rep. Lamar Smith, Chairman

1) **You testified that a robust investment in technology research and development was necessary to improve cost-effectiveness, improve scientific exploration, and increase the cadence of exploration missions. Please elaborate and provide specific examples of the technologies that NASA should pursue.**

NASA-funded technology development efforts provide significant return to its planetary exploration programs, improving or enabling scientific return, reducing mission cost, and improving the pace of our journey. For example, were it not for the New Millennium Deep Space 1 technology demonstration mission that qualified solar electric propulsion for spaceflight, the Dawn mission would not have been an option for the Discovery program. This technology has since been transferred to the commercial satellite industry and today many of our new geostationary communications satellites, critical for much of our daily activities here on Earth, use ion thrusters to meet their orbital propulsion needs. Next year, following years of investment to improve the efficiency of solar-cell technology, Juno, a solar-powered orbiter, will begin its science operations at Jupiter (a distance from the Sun where only nuclear-powered spacecraft were once thought possible). This technology advancement is enabling collection of compelling planetary science by a competitively selected New Frontiers mission at a cost not possible through alternative means. This same high-efficiency solar cell technology is now making its way into other science missions, including the planned Europa Mission.

Technology advancements being pursued in the NASA today will greatly reduce the cost and increase the capabilities of future spaceflight systems. This is particularly true for outer planet destinations where the transit times, distances, radiation environment and surface environments differ so significantly from vistas we have previously visited that new capabilities must be developed. Investing in technology development activities today will bring a broad range of compelling new missions into the realm of possibility, including Discovery, New Frontiers and Flagship class missions to outer planet destinations. Coupled with a heavy-lift launch capability, presently in development by NASA and U.S. industry, an increased cadence of outer planet missions is possible in the decade of the 2020s.

In 2011, NASA developed a series of roadmaps to define technology needs across 14 technology domains, including robotics, structures, power, communications, propulsion, and life support. In 2012, the National Academies completed a Decadal- like review of these technology roadmaps and suggested development priorities for each technology area. Informed by Decadal surveys, these technology roadmaps are under continual refinement by NASA to reflect new mission needs and new technology breakthroughs. In my written testimony, I listed six technology areas (RPS, DSAC, DSOC, TRN, Ocean Worlds Landing Testbed, and HEEET) that are critical to explore our solar system's

ocean worlds or complete other compelling science missions outlined in the Planetary Science Decadal Survey. I believe NASA

should pursue these technologies as well as others listed in the National Academy sanctioned Space Technology Roadmaps (e.g., low mass avionics, high performance computing, and power systems capable of operating reliably at very low temperatures).

2) Do you have any recommendations on how to improve technology development at NASA?

At NASA today, longer-term technology development work is focused within the Space Technology Mission Directorate; nearer-term, science mission technology is managed within the Science Mission Directorate and nearer-term human exploration technology investments is managed within HEOMD. For the advancement of planetary science, this approach requires STMD and SMD to work together and there is ample evidence to suggest that this relationship is working well. This integrated approach to technology development and infusion also implies that the Space Technology budget line must be well funded for NASA's future planetary science missions (and its future human exploration missions) to be advanced. As highlighted in the 2012 National Academies report, funding stability is essential to enable the development of a robust and productive technology portfolio. Without these Space Technology investments, missions to sample the liquid water of one or more ocean worlds, survey the geology of the Venus surface, sail the hydrocarbon seas of Titan, or return to Pluto will likely remain just out of reach.

It takes a different culture (and risk posture) to manage technology investments than to design and operate space science (or human exploration) missions. Within SMD and HEOMD, technology budgets are sometimes utilized as available resources to solve budget issues that arise during mission implementation. In this manner, SMD and HEOMD are incentivized to trade the promise of tomorrow for the reality of today. For these reasons, a separate Space Technology Mission Directorate, focused on the Agency's seed-corn, is a vital part of NASA today. Today, STMD plays a critical role in maturing such technologies to a mission-infusion state.

As recommended in the National Academies Space Technology Roadmaps, to improve the efficacy of NASA's technology development activities, Congress could make it clear as part of NASA's authorization legislation that NASA Space Technology investments must:

1. Balance longer-term (low technology readiness level) and shorter-term (high TRL) investments.
2. Ensure that open competition and public-private partnerships are used more heavily to fully engage innovators in industry and the academic community.
3. Invest in a balanced portfolio of technologies that benefit future NASA missions, as well as the capabilities of the commercial space sector and other government agencies.
4. Take risk and not be afraid to fail.

3) You state in your written testimony that "Planetary science is one of America's crown jewels." Do you believe that, when compared to other science divisions at NASA, the Planetary Science Division receives sufficient funding, or would you prefer to see increased funding for the Planetary Science Division?

While a balanced portfolio of activities within NASA is important, planetary science rises to the top as one of America's unique areas of world leadership. No other country has landed rovers on Mars, explored each planet in our Solar System, viewed Pluto up-close, and begun the exploration of interstellar space. In the past decade, our knowledge and technological capability has advanced to the point that we are on the brink of answering fundamental questions about humanity's place in the cosmos.

The return on investment in planetary science can be felt in both tangible and intangible ways. Just like millions of young people were inspired when we landed men on the Moon, millions more today are inspired by planetary science's role in shedding light on the deepest corners of our Solar System. While we have made considerable progress, there are still many fundamental questions to answer. I believe that significant federal resources should now be directed at these quests. For these reasons, planetary science should be afforded increases at or above the rates for other parts of NASA.

To advance planetary science, we need to return to the outer planets with regularity and consistency of purpose. We need to formulate and implement missions to access the water at destinations in which we know it to exist. It is surprising that today, even considering the work being done towards a mission to Europa, there are no planned missions in NASA's planetary science portfolio that would accomplish this. Just like a future in which we don't follow-up on Kepler's exoplanet discoveries would be hard to conceive, we can't allow a future in which the United States does not send a diverse suite of spacecraft throughout the Solar System, tasting the water on the moons of Jupiter and Saturn, sampling the exotic atmospheres of the outer planets, and touching the earliest remnants of the universe's creation.

4) In April 2013, you co-wrote an OpEd in Space News warning about the U.S. losing its leadership in planetary science, and that after 2017 there will be no U.S. missions to the outer planets. Are you concerned that the U.S. might lose its leadership in deep space exploration because of the President's cuts to planetary science?

Unfortunately, it remains true that after 2017 NASA may only have spacecraft at or on their way to one planet: Mars. This is deeply concerning because a steady cadence of planetary science missions builds U.S. technological capability and demonstrates to the world that the United States is a bold and curious nation interested in discovering and exploring worlds beyond our own for the betterment of all.

It takes at least five years to conceive, design and implement a planetary science mission, and so this cliff is not only upon us, but is getting larger with each passing

day. The next suite of planetary science missions should already be in development. Today, excluding Mars, this gap is at least four years in duration. We can do better.

Robotic exploration of space has emerged as a growing international priority – a way to gain scientific knowledge, global prestige and advance technological capabilities in a way that only planetary science pursuits can do. In the coming decade, China is preparing a series of robotic lunar missions; Russia is preparing lunar, Venus and Mars missions; India is planning to follow-up on its successful Moon and Mars campaigns; Japan is planning a second asteroid sample return mission; the United Arab Emirates is planning a Mars mission; and following up on the flight of the Rosetta spacecraft and Philae lander, the Europeans are developing space systems for exploration of Mercury, Mars, and Jupiter.

To keep the U.S. planetary sciencc program out front, an Oceans Worlds Exploration Program, a well-funded new start for the Europa mission, and an improved cadence of Discovery and New Frontiers solicitations are critical funding priorities. Without sufficient FY16 and FY17 funding for these initiatives, the present four-year gap could reasonably exceed a decade.

5) **In your written testimony, you express dissatisfaction with NASA's current vision of a Europa Mission, stating the "going all the way to Europa without touching its surface is like driving across the country to Disneyland and then staying in the parking lot." Do you believe a mission to Europa is a worthwhile endeavor, even if that mission doesn't include a lander? What science do you hope will be gained from a mission to Europa?**

Because Europa is one of the two worlds in our solar system best suited to search for life as we know it, I believe a mission to Europa is a worthwhile endeavor, even if that mission doesn't include a lander. However, I strongly support including a scientifically focused, short duration landed element to this mission because it is the most definitive way to understand Europa's surface composition relevant to habitability (organic and salt chemistry) and the characteristics (depth, salinity, potential exchange with its interior) of its ocean. In other words, a landed element is the best next step to determine if Europa's ocean harbors and supports life.

I also believe that much like Mars Pathfinder in 1997, inclusion of a small, scientifically focused Europa Pathfinder lander would return great dividends to our nation while infusing a new dose of innovation within our space program. A science- focused technology demonstration that proves our ability to safely and precisely access the fundamentally different surface environment of an ocean world, providing unique imagery and chemical analysis of the icy moon terrain, should be the primary objective of this first U.S. outer planets lander. Such a mission would be a pathfinder for a suite of future surface and subsurface astrobiology missions to access the water in these ocean worlds.

Relative to the cost of a dedicated lander mission, I am confident that the additional cost of a landed element on the Europa mission is small. I am also confident that such a system could be developed in time for launch on the Europa mission.

Recall that prior to flight of the Mars Pathfinder and Mars Global Surveyor missions in 1997, our nation went 20 years without the Mars Exploration Program that today is a central part of our U.S. space exploration identity. Spurred by the technology and implementation advances of these two missions, NASA changed the game at Mars, successfully implementing these missions for approximately ¼ the price of past mission concepts and unsuccessful attempts. These technologies and approaches fueled the creation of today's Mars Exploration Program. In addition to accomplishing its science and technology objectives, Mars Pathfinder established surface mobility and ground truth as important exploration principles, provided a foundational experience for a new generation of Mars scientists and engineers, re- engaged the public with Mars as a destination worthy of exploration, and led to a wide spectrum of small missions to Mars, the asteroids, comets and other bodies in our solar system. I believe a scientifically focused, short duration Europa landed element will do the same.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploration of the Solar System: From Mercury to Pluto and Beyond"

Questions for the record, Dr. Robert Braun, David and Andrew Lewis Professor of Space Technology, Georgia Institute of Technology

Questions submitted by Rep. Donna Edwards, Ranking Member, Space Subcommittee, Committee on Science, Space, and Technology

1) **In your prepared statement, you suggest adding an astrobiology-focused lander to the Europa Clipper mission. Such an addition would add to the cost, and potentially the schedule, of the mission, and could have impacts on NASA's ability to carry out other planetary science activities. How did the National Academies decadal survey treat a lander as part of a Europa mission? How would you suggest this lander be considered? Would this be an opportunity for an international collaboration?**

The decadal survey is our guiding science document, not a detailed mission implementation plan. Just as the decadal survey NASA/ESA 2018 MAX-C lander has evolved into the Mars 2020 lander (while maintaining its science focus), one should expect an evolution in the Europa mission.

In 2009-2011, the National Academies decadal survey developed a consensus behind the science rationale and objectives for a Jupiter Europa Orbiter (JEO) mission that was independently costed at $4.7B. This mission was to complete an orbital tour of the Jupiter system followed by orbital observations of Europa from 100-200 km altitude. The Decadal Survey concluded that NASA should fly JEO only if changes to both the mission and the NASA planetary budget made it affordable without eliminating other recommended missions. In 2012, the JEO Science Definition Team performed a series of studies assessing orbiter, flyby and lander options for Europa exploration. A flyby mission was ultimately selected and independently costed at approximately $2B that spanned a large percentage, but not the full set, of Decadal

Survey science objectives. Key among the missing science objectives is an investigation that makes significant progress in addressing the third question in the Decadal Survey planetary habitats crosscutting theme – "Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?" Clipper will assess Europa's habitability by characterizing the depth and extent of the ocean, mapping some of the surface chemistry, and potentially detecting simple organics on the surface. It will not, however, complete the surface chemistry investigations required to identify complex organics or other biosignatures. These can simply not be achieved via remote sensing. Adding a landed element to Europa Clipper is the best way to determine whether organisms live there now.

Relative to the multi-billion dollar cost of a future dedicated Europa lander mission, I am confident that the additional cost of a landed element on the Europa mission is small. I am also confident that such a system could be developed in time for launch on the Europa mission and sent on its way by the same launch vehicle. The key will be ensuring a focused science investigation that directly and exclusively addresses the above science theme. In my view, inclusion of this landed element as part of the Europa mission to accomplish Decadal survey science is consistent with the Decadal survey guidelines as long as the total mission cost does not eliminate other recommended missions. Congress may choose to request an independent assessment of this question by the Committee on Astrobiology and Planetary Science of the Space Studies Board of the National Academies.

The Europa landed element is a possibility for international collaboration and the European Space Agency has conducted studies to analyze concepts for Europa landers. However, repeated use of Clipper subsystems on the landed element offers potential for cost control and elimination of complex interfaces. Further, as part of a strategy to remain the world leader in planetary exploration, I believe the United States should design, develop, test and implement this system. Recall that it took both Mars Pathfinder and Mars Global Surveyor to create the Mars Exploration Program. Development of a Europa landed element within the U.S. would serve as a critical step in creation of an Ocean Worlds Exploration Program[1].

Successfully operating the first lander on an ocean world is precisely what America has come to expect of its planetary exploration program. Doing so will inspire our children, expand America's scientific and engineering literacy, reinforce our global leadership position, and increase our economic and technological competitiveness.

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[1] In addition to Earth, our present list of ocean worlds includes Jupiter's moons Europa, Ganymede and Callisto, Saturn's moons Enceladus and Titan, and Neptune's moon Triton.

2) NASA's planetary science missions are identifying an increasing number of potential solar system targets at which future planetary missions might seek to detect and study past or present microbial life. Do you have any concerns about the sufficiency or effectiveness of NASA's planetary protection methods for potential life-detection missions? If so, are there changes or technological advancements that might be considered to ensure the efficiency and effectiveness of planetary protection methods?

The National Academies has played a critical role in providing recommendations and support to NASA on this issue and it is imperative that the Academies continue to be engaged in this process. Technology, both within our spacecraft and for planetary protection uses, is rapidly advancing. However, the planetary protection procedures we are using today have not received a major re-thinking in decades and are not entirely up to date with current biotechnology practices in the United States. Heat sterilization practices of the 1970s Viking mission, which largely inform the processes and procedures in place today, are not consistent with the wide range of modern high-tech electronic parts and devices in use today. To move forward, an independent, systems engineering study should be performed that focuses on the intersection of modern microbial science, modern spacecraft fabrication processes, and the credible biological sensitivities of the key planetary science decadal survey destinations. Congress may choose to request such an assessment from the Committee on Astrobiology and Planetary Science of the Space Studies Board of the National Academies.

3) How does the future availability of the Space Launch System (SLS) affect the potential opportunities for scientific exploration of our solar system? What are the primary benefits that SLS would provide for planetary missions?

A heavy-lift launch vehicle would be a game changer for our nation's robotic and human exploration programs and a U.S. strategic capability in a world that is becoming increasingly dependent on space. For robotic missions, such a system will

(1) get spacecraft to their destinations faster, (2) allow inclusion of more science instruments on a given mission or the flight of multiple spacecraft in a single launch, and (3) relax the packaging constraints imposed by our current launch systems. Typically the transit times, or cruise phase, of missions to the outer solar system are in the range of 6 to 8 years because less energetic launch vehicles require our spacecraft to rely on gravity assists from Venus and the Earth in order to gain the energy needed to travel beyond the asteroid belt. In comparison, recent studies have shown that the SLS could propel the Clipper spacecraft to Europa in less than 3 years. It is also capable of lifting both Clipper and a Europa landed element on a single launch. Among other benefits, increasing the cadence of our planetary exploration program would allow for implementation of an Ocean Worlds Exploration Program in which, much like today's Mars Exploration Program, the design and flight of an interconnected sequence of missions to these compelling science targets is possible.

4) **As a university professor, you have the opportunity to work with students on space science and technology. As you know, these students have choices, whether in information technology or other technical fields that don't involve space. Are NASA and the space program attracting enough of these talented individuals to feed a pipeline of experience? Or do we still run the risk of gaps in experience once senior leaders in the field retire? If so, what should be done to address such gaps?**

NASA does an excellent job of motivating young people into educational and career paths in science, technology, engineering and mathematics. In fact, NASA is the clear leader for the United States in this regard. Judging by the passion and creativity of the students I see everyday on the campus of Georgia Tech, this nation's grandest era of space exploration is ahead of us. While it is true that a large number of these young people, originally pointed towards science and engineering by the allure of NASA, choose to go into careers in the biotech or information technology industries, I do not view this as a drawback, but a net gain for our nation in a world that is being more technologically sophisticated each year.

NASA does face a significant workforce challenge. However, this challenge does not stem from a lack of talented individuals trying to get in, but a lack of hiring capacity. With workforce size capped, the NASA Centers are clear examples of this challenge. They simply can't hire enough fresh talent to refill the pipeline. Today, we are running the risk of gaps in technical and leadership experience across NASA because of human resource practices that do not allow the Center workforce to be effectively managed. There are certainly a number of outstanding young engineers and scientists at each NASA Center; however, there are simply not enough of them to create a critical mass of innovation.

Another way to view this issue is to ask how SpaceX, Virgin Galactic, Sierra Nevada, Blue Origin, Planet Labs and other emerging companies have found the talent needed to significantly grow their workforce over the past few years. Imagine if NASA were given the authority to hire even a small portion of this talent base. Our nation's universities are preparing talented young engineers and scientists, in large numbers, for successful careers in the space sector. To reduce the likely gaps in government leadership experience, NASA must be given authority to manage its workforce appropriately and focused on national goals and missions that young people feel are worthy of investing their professional lives.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

STATEMENT SUBMITTED BY COMMITTEE RANKING MEMBER EDDIE BERNICE JOHNSON

Good morning. We have a distinguished panel of witnesses presenting testimony to the Committee this morning, and I want to welcome each of them to this hearing.

NASA's solar system exploration program has been very much in the news in recent days, especially as a result of the amazing flyby of Pluto that has already returned some stunning images of that faraway body. Those images have fascinated the public, and I know that there will more such photos sent back by the New Horizons spacecraft over the coming days and months. I look forward to seeing them.

However, the mission to Pluto is just one of the exciting missions of discovery that NASA has undertaken to better understand our solar system and our place in it. Whether it is rovers on Mars, orbiters around Mercury and Saturn, or a spacecraft voyaging to multiple destinations in the Asteroid Belt, those missions remind us that we truly are in a golden age of solar system exploration.

Yet, while I am proud of the preeminent role the United States has taken in solar system exploration, we are not alone in that quest. And in that regard, I am pleased that international cooperation in this area has been long standing and highly productive. For example, we have cooperated with Europe on a number of challenging missions, including the Cassini-Huygens mission to Saturn and more recently the European Rosetta mission to a comet, for which the United States contributed a number of instruments. And we have worked with other nations as well on other missions.

Mr. Chairman, it is not an overstatement to say that NASA's planetary science program has been extraordinarily successful, and that fact is a tribute to the hard work and perseverance of NASA, its contractors, and the space research community. Yet, Congress also has a role to play in keeping NASA's solar system exploration program robust-namely, we need to do our part by making sure NASA receives adequate and timely funding to support the development and operation of those challenging missions. And we need to make sure we are also providing the funding needed to develop the advanced technologies that will enable the future missions that will continue to rewrite the science textbooks.

Well, we have much to discuss today, and thus I will yield back so that we can hear from our witnesses. Thank you.

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